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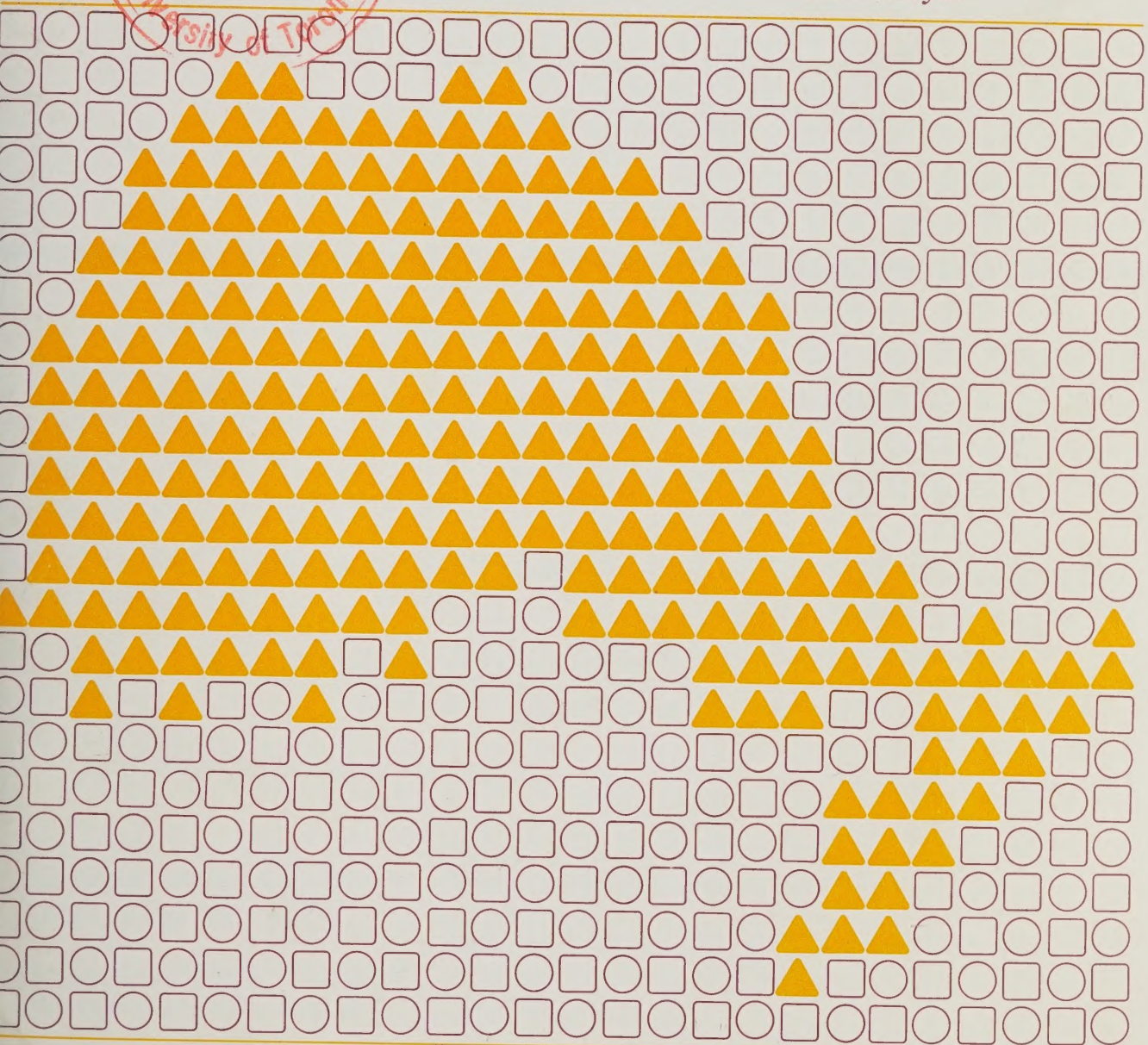
Volume 6, Number 3, Summer 1985

A Noise Standard – Evidence Review

A Quality Grading Code for Spirometry

Swipe Sampling for Polychlorinated Biphenyls

Health Effects of Occupational Exposure to Formaldehyde



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Occupational Health in Ontario

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Ihor Taraschuk, M.D., P.Eng.

A Noise Standard – Evidence Review*

Summary

Noise and hearing loss measurements are defined. Evidence on noise dose versus *hearing loss is reviewed.*

Introduction

Noise is not a new hazard. In 1770 Ramazzini, in 'De Morbis Artificium Diatriba', described how those hammering copper 'have their ears so injured by that perpetual din . . . that workers of this class become hard of hearing and, if they grow old at this work, completely deaf.'[1] Hunter[2] references Forbroke's comments in an 1831 edition of the *Lancet* to substantiate his claim that it was known early in the nineteenth century that 'no one obliged to work in the interior of a boiler while riveters are hammering outside escapes impairment of hearing for any length of time.' Thus for over two centuries society has known about noise-induced hearing loss. Yet, if one examines the most recent annual reports[3] of the Workers' Compensation Board of Ontario, one finds that the number of new pensions for noise-induced hearing loss is increasing year by year. As can be seen from Table 1, the board allowed 1,381 new claims in 1983. It can therefore be argued that there is a need for a noise standard. This paper shall briefly review the evidence for the development of such a standard. The reader should bear in mind that any occupational health standard must include definitions of:

a) the offending agent and its method of measurement;

b) the harmful effect (i.e. what is the standard trying to prevent?);

c) risk (i.e. a statement concerning the postulated or proven relationship between a dose of the offending agent and the harmful effect);

d) permissible exposure level (i.e. how much of the offending agent is permitted to be present in the work environment?);

e) a control program (i.e. engineering controls, protective equipment, administrative controls, medical surveillance, etc.); and

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* Based on a thesis submitted to the Canadian Board of Occupational Medicine in partial fulfilment of the requirements for certification.

f) an evaluation program (having applied the standard, how will one determine if the desired effect is being achieved and if there is a need to modify the standard?).

Table 1

Number of New Pensions for Noise-Induced Hearing Loss as Determined by the Workers' Compensation Board of Ontario.

Year	# of new pensions
1980	830
1981	955
1982	1332
1983	1381

Finally, let us not forget that the review of evidence for the development of any occupational health standard is not complete unless it takes into account the engineering feasibility, the economic impact and the effects that the particular standard will have on the potentially conflicting rights of the employees, the employers and society as a whole. Exceedingly strict standards that take away an industry's competitive edge and overly permissive standards that lead to a disease-ridden work force do society no favours.

All of the above factors influence each other and should therefore be taken into account in an evidence review. However, due to space constraints, only the first three topics listed will be discussed, namely: a definition of noise and its measurement, a definition of harmful effect and a definition of risk.

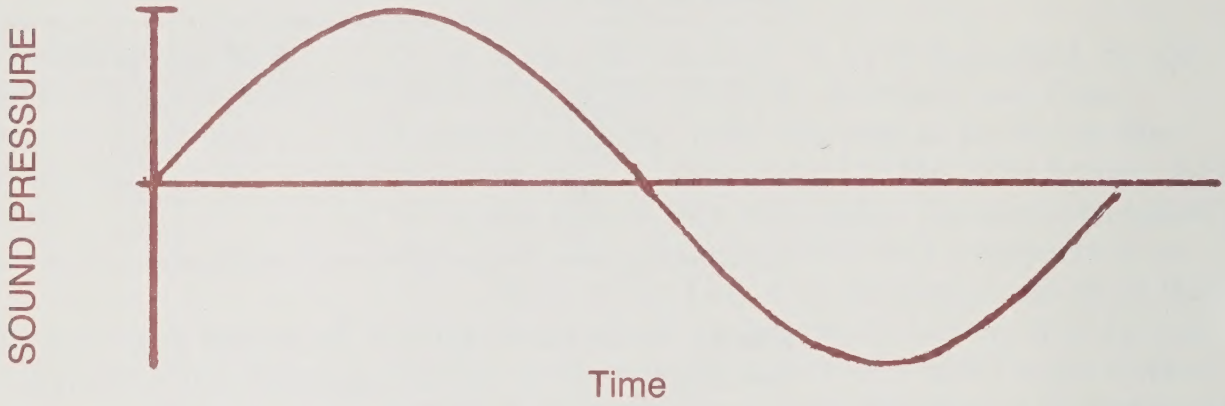
Definition of Noise and Its Measurement

Noise may be defined as an unwanted sound. Shortley and Williams[4] define sound as 'a mechanical wave motion in an elastic medium.' Some of the fundamental principles of wave mechanics and noise measurement may be illustrated by analysing a sound wave produced by a tuning fork. For a more formalized and precise treatment, the reader is referred to standard textbooks on this subject.[5–7]

If one strikes a tuning fork and measures the changes in atmospheric air pressure in its vicinity, one will obtain a waveform that is illustrated in Figure 1. The number of times that this waveform repeats itself in one second is called cycles per second (cps), or Hertz (Hz), and is known as frequency. A given sound wave may have a single frequency or a range of frequencies. Therefore,

when measuring a given sound, one specifies a frequency range or band width. For example, if one measures an octave band of centre frequency 4,000 Hz, one is measuring between 2,840 and 5,680 Hz.

Figure 1 **A Tuning Fork Generated Sound Wave**



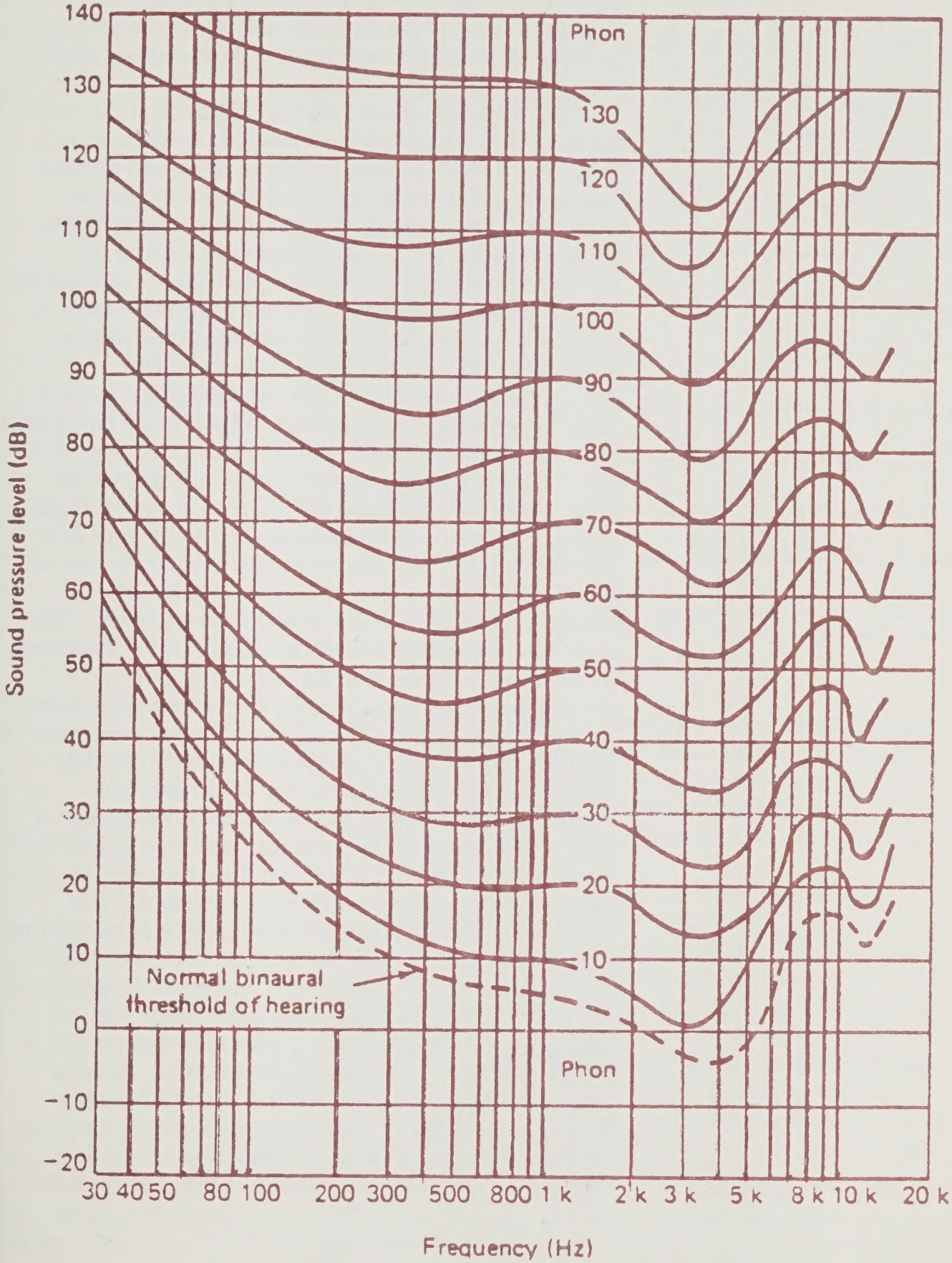
Returning to Figure 1, it is noted that the amplitude of a sound wave may be measured by recording its pressure. Normally, scientists would have specified this pressure in Pascals (Neutons per metre squared). However, when they attempted to relate this pressure measurement to the performance of the human ear, it was found that the quietest sound that could be heard by an average person at 1,000 Hz had a pressure of about 20×10^{-6} Pascals; and that pain was produced at a pressure of about 100 Pascals. Remarkably, the human ear hears sounds throughout this vast range. Since the ratio of the highest to the lowest measurement was more than one million to one, a linear scale of measurement was impractical. Furthermore, when a large number of subjects were tested to obtain equal loudness curves (see Figure 2), it was found that the ear responded in a non-linear fashion to both frequency and pressure. Therefore, a new unit, called a decibel (dB), was defined, and it was found that a rise of 10 dB in sound pressure level corresponded to a doubling of subjective loudness. Sound pressure level (SPL) in decibels was defined by the following formula:

$$SPL = 20 \log_{10}(p/p_o)$$

where SPL = sound pressure level in decibels
p = the root mean square of sound pressure being measured
$p_o = 20 \times 10^{-6}$ Pascals (a reference pressure)

This produced a scale of measurement that had a range of 0 to 140 as shown in Figure 2. It had the added

Figure 2 **Equal Loudness Curves**



advantage that sound pressure level was proportional to the energy passing through a unit of space. It should be noted that if one doubles the sound pressure (i.e. introduces another machine into the plant) one gets an increase in sound pressure level of 3 dB and not double the previous dB level.

If one examines the contours of Figure 2, it becomes apparent that the sensation of loudness depends upon frequency as well as sound pressure level, and that the human ear is less sensitive to low frequency than to higher frequency sounds at equal sound pressure levels. Furthermore, as the sound pressure is increased to moderate levels, the ear starts to place more emphasis on low frequency components, and the large differences in sound pressure levels between low and mid-frequency judgements begin to lessen. Having made these observations, scientists decided to relate physical noise measurements to human perception by filtering (weighing) these levels across frequencies in a manner analogous to the spectral response characteristics of the human ear. Thus an 'A' weight function (filter), as shown in Figure 3, was proposed. Comparing Figure 3 and Figure 2, it may be that the 'A scale' is the approximate inverse of the 40 phon contour, and therefore simulates the sensitivity of the ear at low sound pressure levels. This scale has been internationally standardized for measuring sound pressure levels with respect to people's psychophysiologic perception of sound.[8] Sound pressure levels that are measured using this filter are given units of dB(A) where the (A) means that the sound wave has passed through a filter having an 'A' weighting.

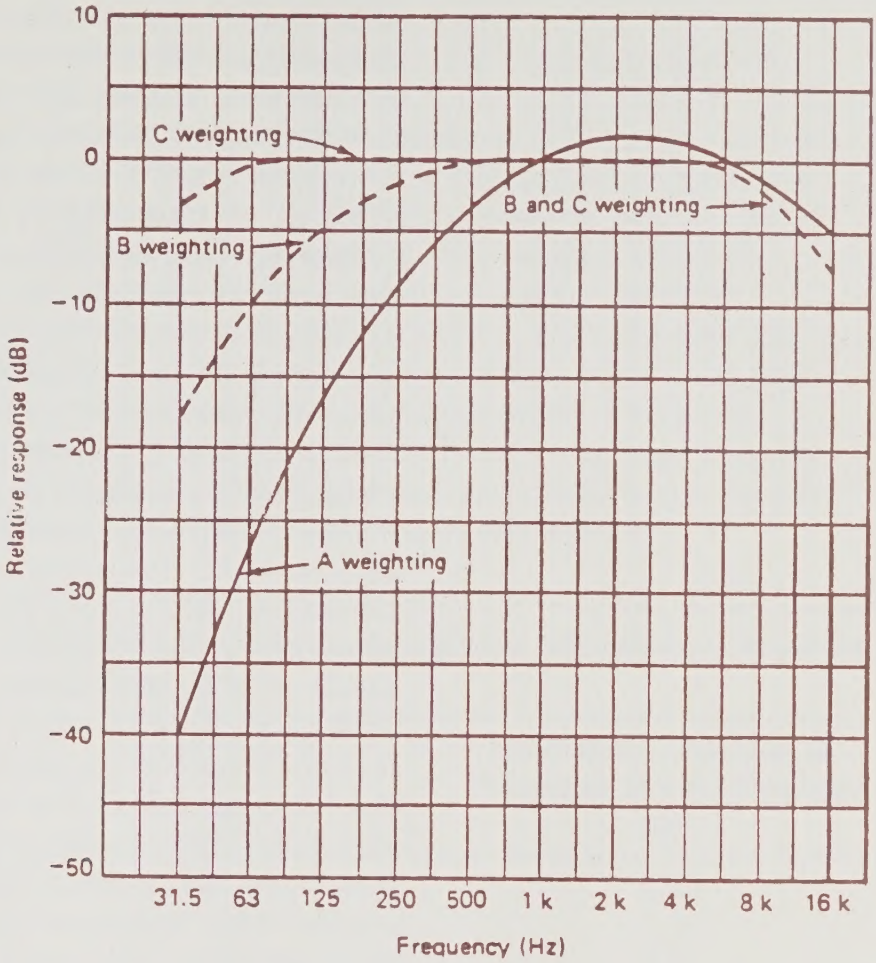
Using the above information, a person's exposure to noise could be measured provided that the sound pressure level and the exposure time did not vary excessively. If these parameters do vary excessively, then multiple readings, at specific instances that a person is exposed to each sound level, have to be taken and correlated with the exposure times. Giardino and Seiber[9] have noted that this task can be performed using a dosimeter (i.e. an integrating circuit coupled to a sound level meter and a timer). The use of a dosimeter forces one to define a time-intensity relationship. Several such relationships have been postulated. Reasons for their differences will be discussed later. One such relationship defines L_{eq} (equivalent sound level) by the following formula:

$$L_{eq} = 10 \log(1/T) \int_0^T 10^{(L/10)} \, dt$$

where T = the period of observation
L = the A weighted sound pressure level

Figure 3

A Weighting Scale



Note that if L_{eq} is to stay constant, then L must decrease by 3 dB for each doubling of time. This relates to the 3-dB rule. It is also possible to construct a 5-dB dosimeter, in which case, L must decrease by 5 dB for each doubling of exposure time. Thus we have a method for measuring noise dose.

Finally, it should be noted that there are impulse sounds. These are associated with various events such as drop forging, hammering, gun shots, etc. These sounds achieve a peak sound pressure level in less than 35 milliseconds (rise time), and within 500 milliseconds the sound pressure level falls at least 20 dB below peak. Special techniques are required for the measurement of impulse sounds and for evaluation of their perceived loudness, annoyance factor and hearing damage risk. Due to space constraints, impulse noise will not be discussed.

Definition of Harmful Effects

What are the harmful effects that our standard is to prevent? The International Labour Organization (ILO) Encyclopedia of Occupational Health and Safety[10] divides these effects into non-auditory and auditory groups.

A. Non-Auditory Effects of Noise

These may be discussed under such headings as physiology, behaviour, annoyance, efficiency, absenteeism, fatigue, and mental health. A popular postulate is that noise above a certain level can increase the release of ACTH, thereby raising the corticosteroid level (i.e. a stress reaction by way of the hypothalamic pathways). This mechanism is used to explain the significant increases in blood pressure that have been reported in workers who are exposed for a long time to high levels of noise. Similarly, the increased gastrointestinal motility produced by intense sounds is used to explain the higher prevalence of peptic ulcers, which have been observed in noise exposed groups.

Hattis[11] noted that 'When non-auditory effects of noise are examined, it is apparent that although there is a substantial body of data that suggests a wide variety of noise-induced health effects of potentially great significance in social terms, the scientific evidence for most or all of these effects is far from conclusive.' The ILO encyclopedia[10] supports this conclusion by stating that 'Considerable further study is required in order to be able to comment on their significance.' For the above reasons the non-auditory effects are not taken into account when setting an exposure standard. As expected, there are groups who don't agree with this and argue for their inclusion.

B. Auditory Effects of Noise

In order to discuss the effects of noise on hearing we must review the definition of normal hearing and its measurement. The following material is based on William Burns's book *Noise and Man*.[12]

Consider an experiment where a pure tone that lasts approximately one second is presented to a subject by means of an earphone. The subject is requested to signal when he hears the tone. There is an intensity at or above which every signal elicits a response. Similarly, there is an intensity at or below which no signal elicits a response. The size of this range varies from 2 to 6 dB depending on the individual tested.

In another experiment we start with an easily audible intensity and decrease it until the subject hears only 50 per cent of the signals. The level reached is known as the descending threshold. Similarly, an ascending threshold could be determined. It is of interest that the descending threshold is lower than the ascending one.

The above experiments were repeated using as subjects young people between 18 and 25 years of age who had no otological abnormalities. The hearing threshold obtained from these groups was used to standardize audiometers. In other words, the audiometer, when set at zero dB, will generate a signal that 50 per cent of the above group would hear. The International Standards Organization has agreed on a reference zero for the calibration of audiometers. The standard deviations obtained by Dadson[13] while conducting such an experiment are shown in Table 2. One will note that, at 4,000 Hz, five per cent of the subjects had more than a 14-dB variation from the group mean. The above illustrates how an individual's data may vary from the mean value of a given group and points to the need for individual baseline (reference) audiograms.

Table 2 **Standard Deviations of Auditory Thresholds. (Dadson and King, 1952)**

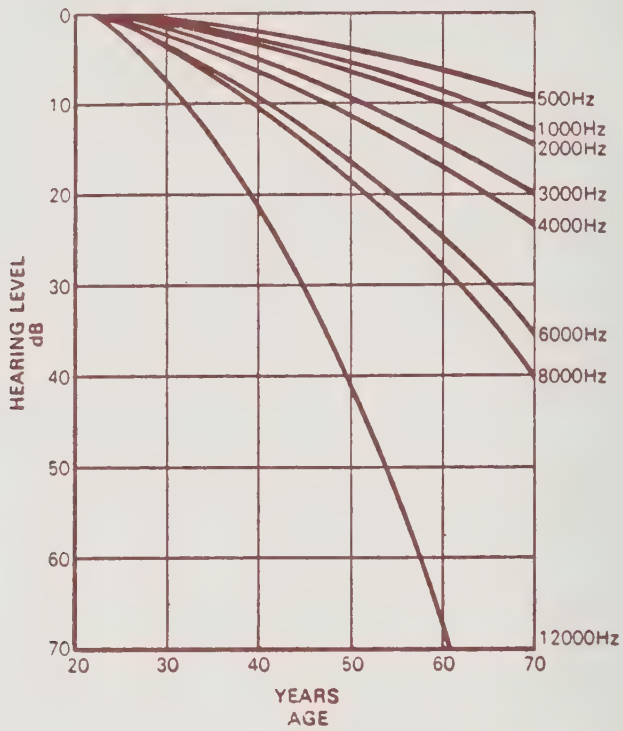
Frequency Hz	Standard Deviation of Threshold Sound Pressure dB
123	6.8
250	7.3
500	6.5
1000	5.7
2000	6.1
4000	6.9
6000	9.1
8000	8.7

This brings us to the question of how a given individual's audiogram varies from test to test. Brown[14] investigated this by comparing audiograms that had been taken on 30 subjects 1 hour apart. He obtained standard deviations of approximately 4 dB in the frequency range 125 to 4,000 Hz and a 5-dB deviation at 8,000 Hz. Others confirmed that, with well-conducted audiometry, a change of 10 dB between audiograms should be regarded as possibly significant.[12] It has been suggested that this standard deviation could be reduced to 4 dB by obtaining averages from multiple audiograms.

Finally, hearing loss due to age has to be taken into account. Hinchcliffe[15] investigated this situation, and his results are shown in Figure 4. Glorig and Davis[16] examined the same problem using air and bone conduction audiometry and came to the conclusion that

part of the age deterioration (presbycusis) is in the middle ear and therefore distinct from the deterioration due to noise. Therefore, it would be reasonable to treat the effect of noise and the effect of age as independent events.

Figure 4 **Relationship Between Age and Mean Hearing Level**



When a person is subjected to noise, and the effects are measured using the above methods, three common responses may be obtained. They are temporary threshold shift, permanent threshold shift and acoustic trauma. The evidence for these will be briefly reviewed.

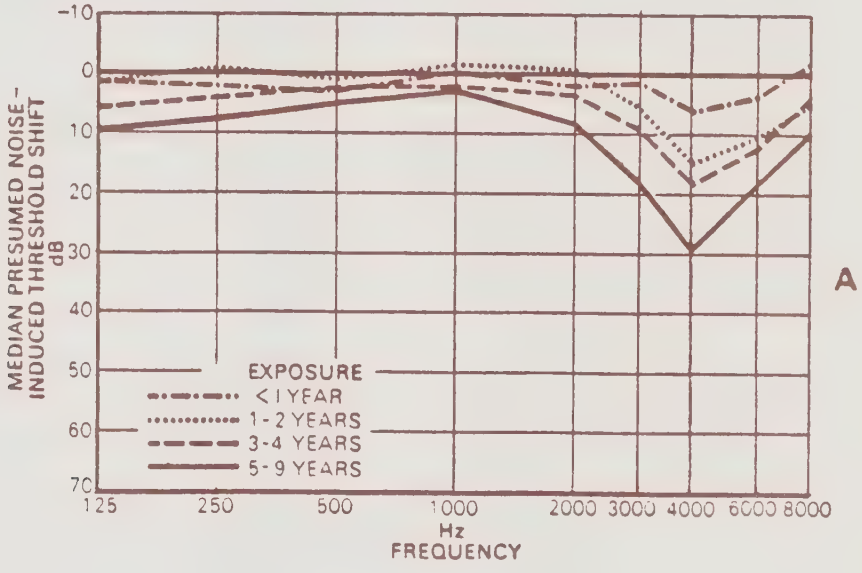
The case of acoustic trauma is illustrated by Ward and Glorig[17]. A short-term or sudden intense exposure may cause immediate aural damage with hearing loss.

Ewing and Litter[18] demonstrated that when a person is exposed to a tone of a given frequency, a hearing loss occurs that ranges from that frequency to frequencies about one octave higher. They noted that this effect was reversible with time and that there was marked variation of susceptibility between individuals and even between the ears of the same individual. Since the above phenomenon is reversible, it is known as temporary threshold shift.

Taylor[19] examined a group of workers who were exposed to relatively constant noise levels for varying periods of time (1 to 40+ years). After correcting the threshold shifts for age, a noise dose relationship, as

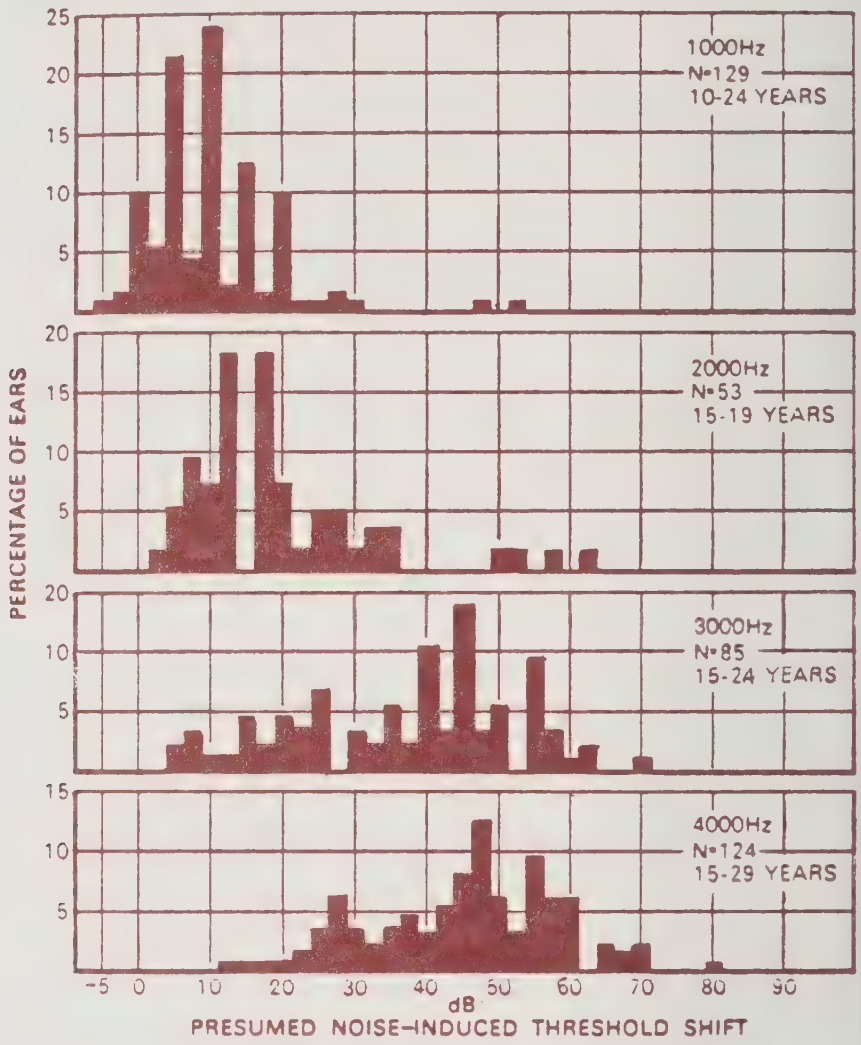
shown in Figure 5, was obtained. From Figure 5 the reader will note that a threshold shift at 4,000 Hz is the first sign of noise-induced hearing loss. This loss expands to other frequencies as the noise dose increases. The above observations have been confirmed by others, such as Nixon.[20] Taylor also obtained a distribution of noise-induced permanent threshold shifts for a group of workers exposed to a given noise dose, as illustrated in Figure 6. The reader will note that some people showed little or no effects and that others who had received the same noise dose deteriorated significantly. Some of this variability could be attributed to audiometry (as discussed earlier); however, the fact remains that noise exposure, which may seriously affect some people, is apparently innocuous to others.

Figure 5 **Mean Hearing Loss as a Function of Noise Dose**



Having reviewed the effects of noise on hearing we are now left with the problem of what our standard should be designed to prevent. It could first be argued that the aim should be to avoid any noise-induced hearing loss. Unfortunately, as discussed earlier, there is a variability in response to noise dose. Therefore, a restriction of exposure that would allow no deterioration whatsoever, at any audiometric frequency, would overprotect the less susceptible majority. Workers would be needlessly inconvenienced by being forced to wear hearing protection and industry would be needlessly burdened by being forced to invest in protective equipment, engineering controls and medical surveillance programs. Furthermore, such an approach might not benefit the people whom we are attempting to protect. For, as noted

Figure 6 **Variations of Hearing Loss for a Given Noise Dose (Taylor, 1965)**



by Glorig,[21] damage that is not noticed by the individual will not produce a noticeable difference in the operational efficiency of functions that are required for normal life. For example, it has been demonstrated[22] that a moderately large threshold shift at 4,000 Hz produces no handicap in everyday living. Indeed, it does not even interfere with the appreciation of music. Therefore, it could be argued by some people that protecting against a slight threshold shift at 4,000 Hz would result in an exceedingly strict standard.

Using arguments such as the above, it can be shown that a noise standard should be set so that it protects the ability to hear and understand speech. How to relate this to pure tone audiometry has been discussed by the American Academy of Otolaryngology.[23] They claim that an average of hearing threshold values should be obtained at 500, 1,000, 2,000 and 3,000 Hz for each ear. The amount by which this average threshold exceeds 25 dB is

multiplied by 1.5 per cent to obtain the per cent impairment for each ear. The better ear is given a weighting of 5; the impairments are averaged and divided by 6 to obtain the overall impairment. The Workers' Compensation Board of Ontario allows a claim for noise-induced hearing loss if the average threshold shift at 500, 1,000, 2,000 and 3,000 Hz minus one-half the age in years over 60 is greater than 25. A loss of over 35 dB is considered pensionable.

We now come to the question of how much noise exposure may be permitted in order to achieve the above results. In other words, what is the risk?

Definition of Risk

In September 1939 a study was published on 'The effects of aeroplane noise on the auditory acuity of aviators.'[24] Using clinical tests, this study measured the effects of noise dose on threshold shift. The noise dose was varied by use of ear plugs. The conclusions of this study are quoted below:

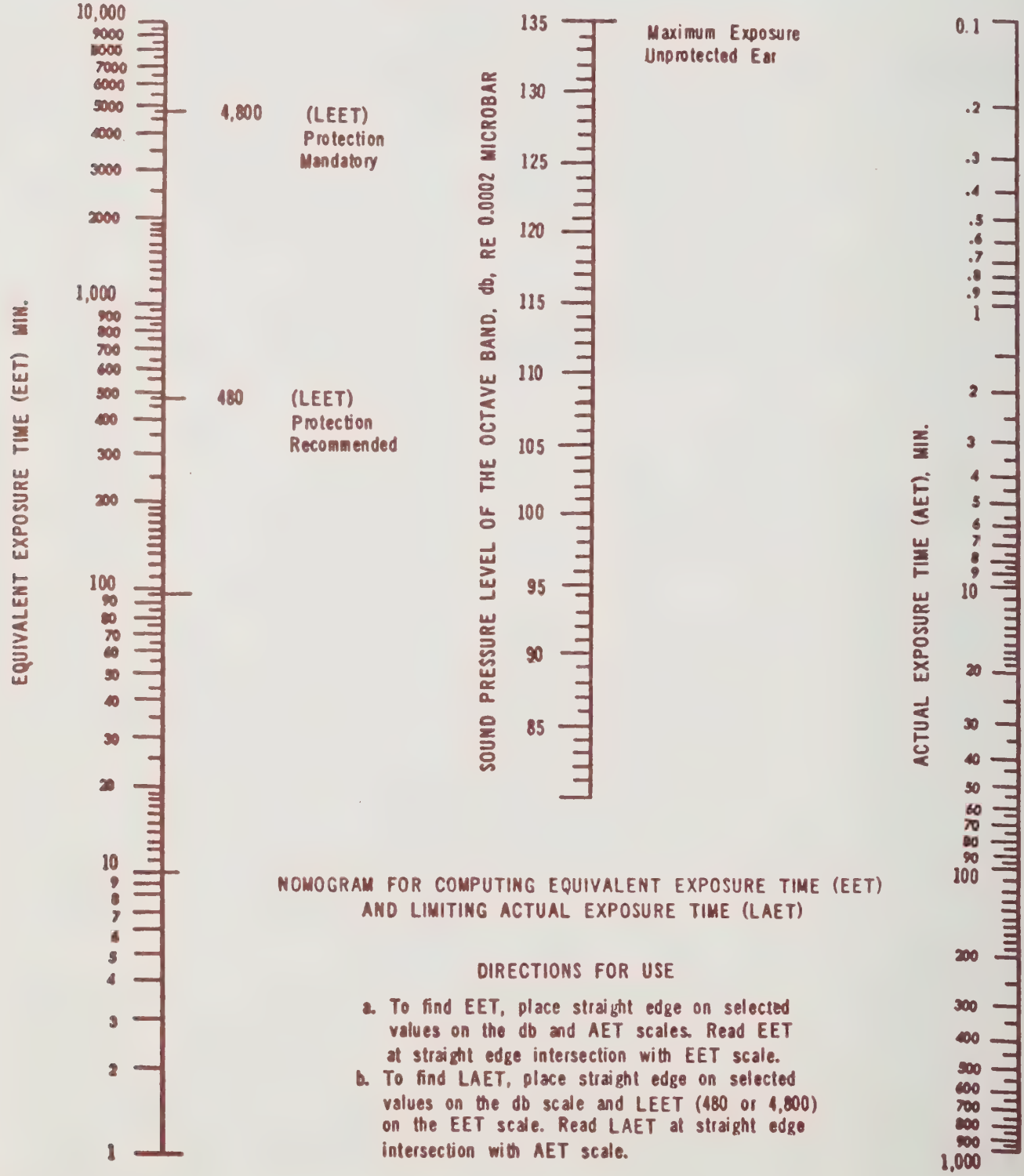
1. A loss of high tones is noted in persons exposed to aeroplane noise if the ears are not protected.
2. This loss becomes apparent at an early stage, even after a few hours. It varies with individuals, and is temporary at first, but becomes permanent after time.
3. No deafness amounting to disability is complained of unless the speech frequencies are involved.
4. Bone conduction is diminished *pari passu* for frequencies showing a loss of air conduction.
5. Wave analysis of aircraft noise, by existing methods, indicates that all of the components of large amplitude are of low frequency. There is thus an apparent inconsistency with evidence obtained in experiments on aural fatigue and cochlear degeneration as the result of noise, in which depression of the response has occurred at or about the frequency of the fatiguing tone.
6. Protection of the ears appears to diminish, if not eliminate, the risk of impairment of auditory acuity as measured by the audiometer.

The above illustrated that if the noise dose is reduced, the risk for developing hearing loss diminishes.

On the basis of such evidence, it is not surprising that the United States Air Force published Regulation No. 160–3.[25] This regulation tackled everything from hazard assessment to medical testing and worker removals, and

endorsed the equal-energy assumption, thereby implying that all exposures involving a given total amount of energy (in a given octave band) are equally noxious. Thus, if 85 dB of SPL is tolerable for an 8-hour steady exposure, then a level of 88 dB would be permitted for 4 hours, 91 dB for 2 hours, 94 dB for 1 hour, and so on. A Nomogram for computing Equivalent Exposure Time and Limiting Actual Exposure Time is shown in Figure 7.

Figure 7 **U.S. Air Force Nomogram for Computing Permissible Exposure Level**



Since the air force was using a 3-dB rule, it did not differentiate between a 1-hour exposure to 94 dB and 12 five-minute exposures occurring once every half hour. However, these different exposure patterns led to different magnitudes of temporary threshold shift.[26] It was therefore argued that it would be highly unlikely that these exposures would produce equal noise-induced permanent threshold shifts. Instead, these same people claimed that it was reasonable to assume that daily noise exposures that produce equal temporary threshold shifts will eventually result in equal values of permanent threshold shift.

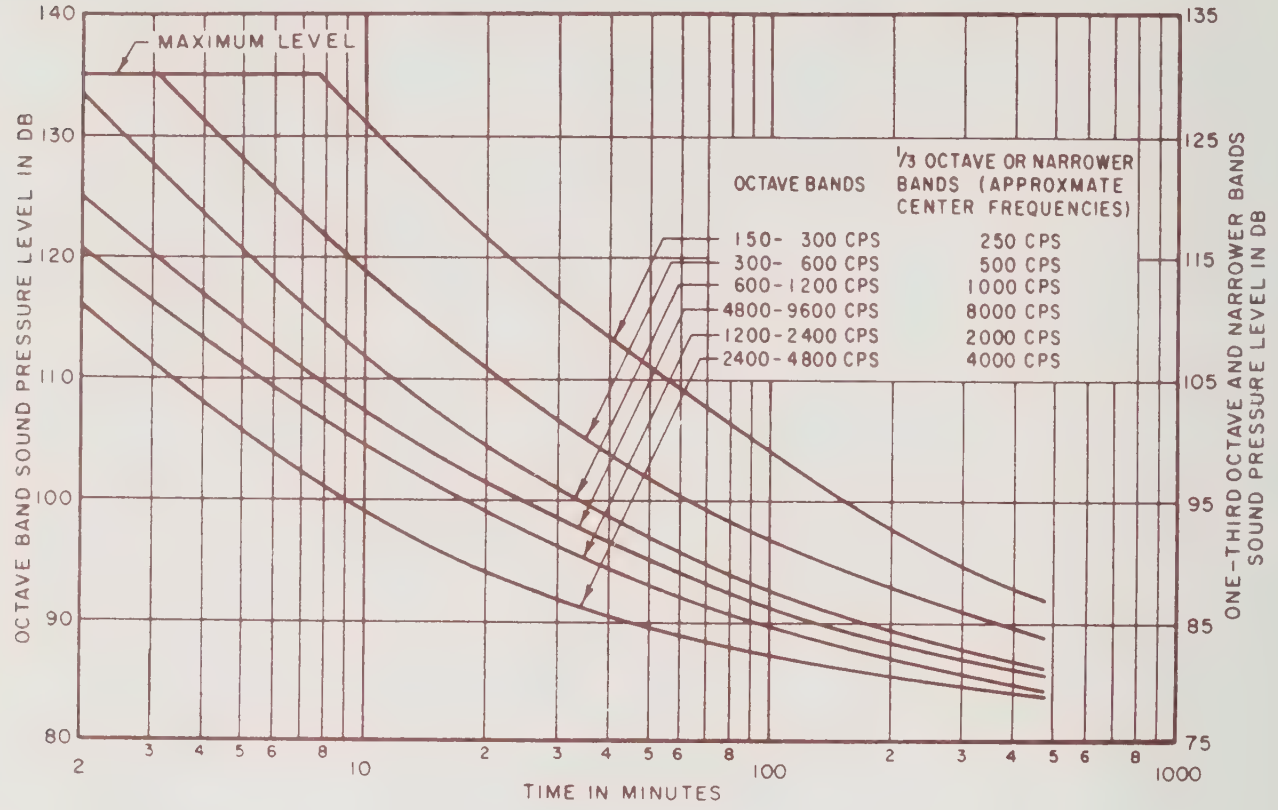
In view of the above controversy, it was not surprising that The Office of the Surgeon General, U.S. Army, requested the National Academy of Science – National Research Council Committee on Hearing Bioacoustics and Biomechanics (CHABA) to re-evaluate the question of damage risk criteria for exposure to sound. The committee responded by publishing graphs[27] of maximum sound pressure levels *versus* duration of exposure (see Figure 8). While attempting to prepare these graphs, the committee noted that 'there are good data relating NIPTS [noise induced permanent threshold shift] to exposures to broad-band, steady noises incurred daily, 8 h per day for years. Maximum tolerable exposures to the same noises can be specified for the NIPTS criterion directly from the data. Comparable data do not exist for many shorter exposures to noise, for exposures to intermittent noise, or for repeated short exposures with intervening rest periods; but an assessment of these classes of exposures can be made in terms of temporary threshold shift produced in young normal ears by noise exposures that are comparable to those encountered in a single working day in the industrial studies of NIPTS.'[27]

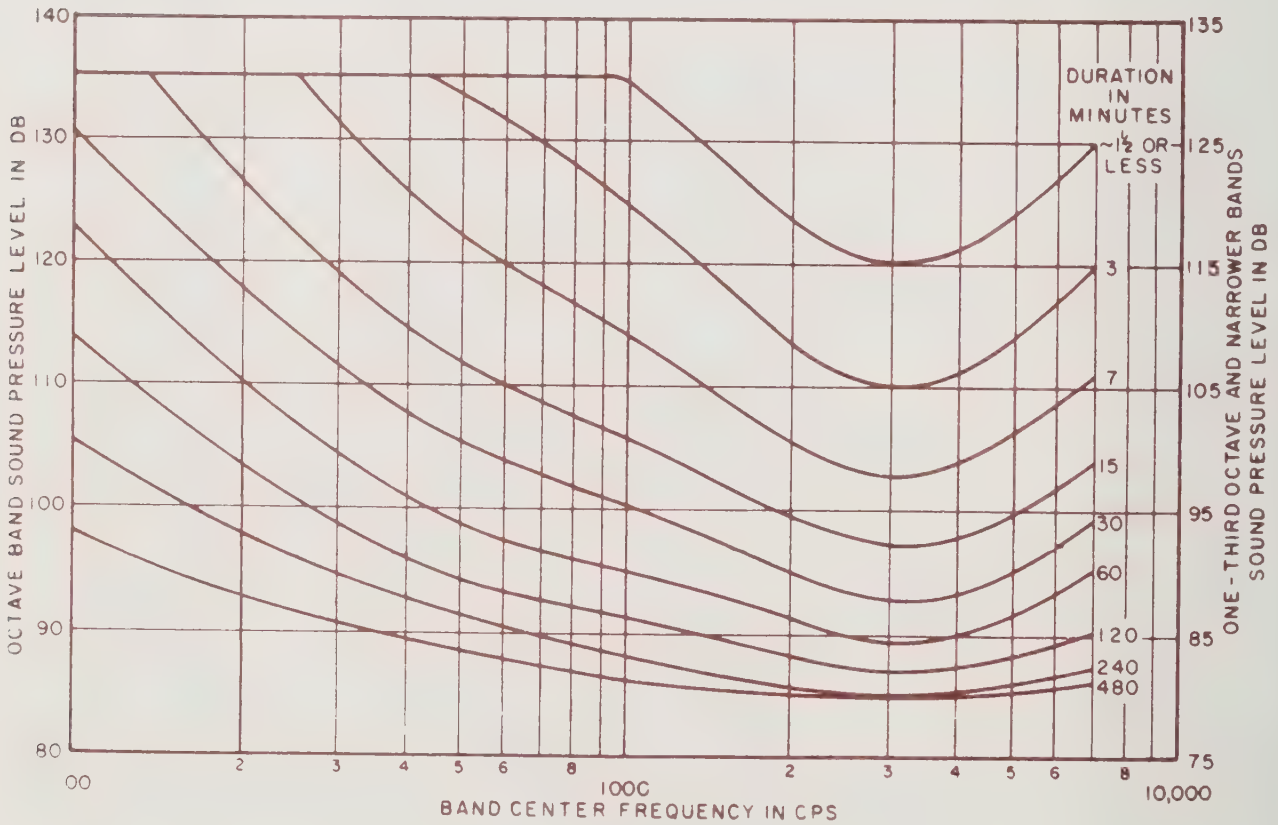
Therefore, in order to arrive at the above graphs, the committee had to assume the following three postulates:

1. The temporary threshold shift 2 minutes after the end of the exposure (TTS_2) is a constant measure of the day's exposure.
2. All exposures that produce equal TTS_2 are equally hazardous.
3. The noise-induced permanent threshold shift (NIPTS) eventually produced by 10 years of daily exposure to a given pattern of noise is approximately equal to the TTS_2 produced by an 8-hour exposure to the same noise pattern.

Approximately one year later, Botsford[28] published a substantial simplification of the CHABA contours as

Figure 8 CHABA Contours

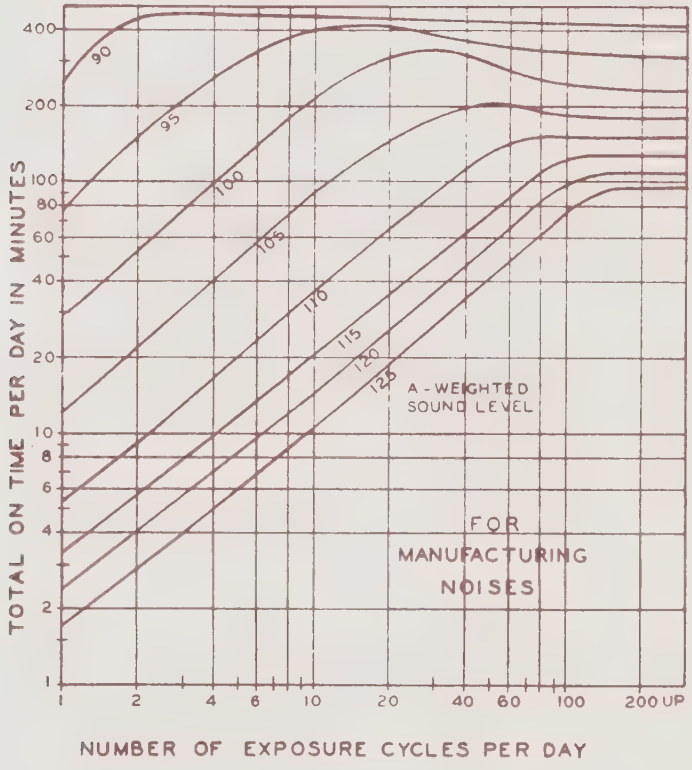

MAXIMUM LEVEL
OCTAVE BANDS
1/3 OCTAVE OR NARROWER BANDS (APPROXMATE CENTER FREQUENCIES)
150- 300 CPS 250 CPS
300- 600 CPS 500 CPS
600-1200 CPS 1000 CPS
4800-9600 CPS 8000 CPS
1200-2400 CPS 2000 CPS
2400-4800 CPS 4000 CPS
OCTAVE BAND SOUND PRESSURE LEVEL IN DB
ONE-THIRD OCTAVE AND NARROWER BANDS SOUND PRESSURE LEVEL IN DB
TIME IN MINUTES



shown in Figure 9. Using 580 industrial noises, he demonstrated that the 'A-weighting' sound pressure level predicted the hazard to hearing as accurately as did limits expressed in octave band sound pressure levels. While on this topic, it should be noted that Robinson[29] examined 759 subjects and concluded that the error incurred from using dBA to predict hearing loss was within ±2 dB. Cohen *et al.*[30] found that the dBA scale predicted TTS_2 as well as, or better than, other noise rating schemes. Therefore, it is not surprising that there is general agreement on the use of the dBA scale for measurements involving noise hazard assessment.

Figure 9

Total Duration of Allowable Noise During an 8-Hour Day as a Function of the Number of Periodic Interruptions



Armed with the above information, we are ready to examine the 1967 Guidelines of the American Industrial Hygiene Association.[31] For constant noise exposures, the association based its conclusions on industrial experience and arrived at a suggested permissible exposure level of 90 dBA. When faced with the problem of intermittent exposures, they could not find long-term studies that dealt with this problem. Therefore, they used the same approach as CHABA and generalized from TTS data,

which is shown in Figure 10. From Figure 10, the reader will note that one is permitted 20 minutes of exposure time, with an off time of approximately 7 minutes at 95 dBA. At 100 dBA this changes to 10 minutes, and at 105 dBA, to 5 minutes. Thus, the association arrived at a table of permissible increases in dB for less than 8 hours of exposure, as shown in Table 3. The reader will note that Table 3 follows the 5-dB rule and is similar to the permissible exposure levels as prescribed by section 144 of the Ontario Regulation for Industrial Establishments.[32] The prescribed levels are illustrated in Table 4.

Figure 10 **Permissible Exposure Dose Based on TTS**

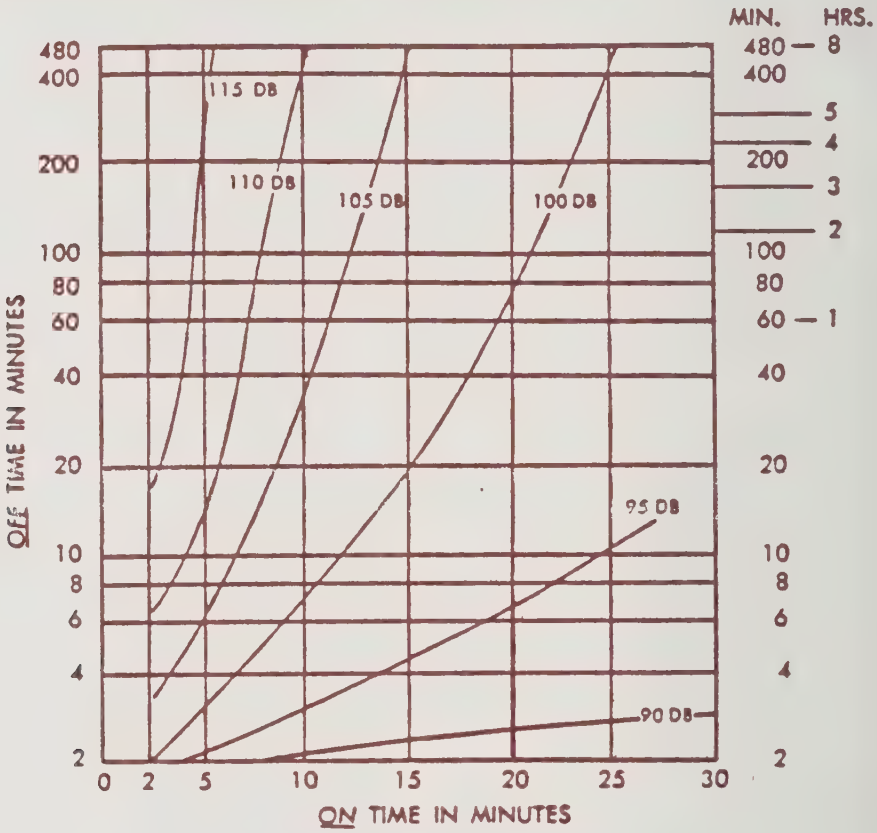


Table 3 **Permissible Increase in dB for Less Than Eight Hours' Exposure. (AIHA Guidelines, 1976)**

Daily Exposure Time (Hours)	Permissible Increase Above Eight-Hour Criterion (Decibels)
8	0
4	5
2	10
1	15
1/2	20
1/4	25

Table 4

Permissible Exposure Times as Prescribed by the Ontario Ministry of Labour. (Ontario Regulation 658/79)

Sound Level (Decibels)	Duration – Hours per 24-hour Day
90	8
92	6
95	4
97	3
100	2
102	1 1/2
105	1
110	1/2
115	1/4 or less
Over 115	No exposure

Having reviewed the evidence for the 5-dB rule, let us examine the evidence for the 3-dB rule. An elegant proof of the 3-dB rule comes from the work of Burns and Robinson.[33] As noted previously, this study used 759 noise-exposed persons and 97 young non-exposed controls. All subjects were given otological examinations, and those with abnormalities were excluded. The noise exposure ranged from one month to 50 years, with sound level pressures from 75 to 110 dBA. The noises were non-impulsive in type. The noise-exposed subjects were divided into 20 groups, each representing a narrow range of intensity and duration. For each group, the mean age-corrected hearing levels at 3,000, 4,000 and 6,000 Hz were obtained. These levels were plotted against various indices of exposure. Without going into the mathematical details, it may be stated that the above study concluded that age-corrected hearing levels could be predicted for noise exposed groups, provided that the formula for noise emission level (noise dose) was defined as follows:

$$NIL = L_A + 10 \log_{10} T$$

where: NIL = Noise Emission Level,
L_A = A weighted sound level, and
T = Exposure Time.

The reader will note that if NIL is to stay constant, then for every doubling of T, L_A must decrease by 3 dB. Hence, the 3-dB rule. Please note the similarity between L_{eq} and NIL.

Therefore, we have two different exchange rules that lead to two different types of dosimeteres. Which one

should we choose? Bear in mind that there are two groups, each supporting a different rule.

Without quoting the massive amount of work published on the above topic, it can be simply stated that there is no good evidence upon which to establish a precise relationship between TTS_2, or TTS_{100} for that matter, and permanent threshold shift. Hence the objection to the 5-dB rule.

On the other hand, there are those who argue that intermittent exposures and the potential for recovery were not taken into account when developing the 3-dB rule. To resolve their concerns, one would have to find a group of people exposed to an intermittent noise and repeat the Burns-Robinson experiment. Unfortunately, this has not been possible. Hence the objections to the 3-dB rule.

Conclusions

Two approaches may be taken to resolve the above problem. One approach follows the advice of Ward[34] and takes up animal studies: In these studies the experimental conditions can be precisely controlled. Ward has done this using chinchillas, and has indicated that if these studies are expanded to other species it might be possible to demonstrate 'whether the equal-energy theory should be applied to man.' One can wait for the results of these studies and then propose a standard.

Another approach is to propose a regulation that uses either one rule or the other and which insists on noise dose measurements and on medical surveillance. By evaluating the results in 20 years time, one would be able to determine if changes are required.

Both of the above approaches have advantages and disadvantages. Therefore, it is only proper that the politicians shall decide and the courts shall interpret.

Résumé

Ce document définit les mesures utilisées pour déterminer l'intensité du bruit et la perte de l'ouie. Il fait également une étude *comparative* entre la durée et l'intensité de l'exposition au bruit et la perte de l'ouie.

References

[1] Ramazzini B. De Morbis Artificium Diatriba. Cited in NIOSH, Occupational Exposure to Noise. U.S. Department of Health, Education and Welfare, Washington. 1972; II-1.

[2] Hunter D. The Diseases of Occupations. 5th ed. London: Hodder and Stoughton, 1975. 833.

[3] Workers' Compensation Board of Ontario, Annual Report, Toronto, Ontario. 1983.

[4] Shortley G, Williams D. Elements of Physics. 4th ed. Englewood Cliffs, N.J.: Prentice-Hall Inc, 1960. 442.

[5] Irwin J, Graf E. Industrial Noise and Vibration Control. Englewood Cliffs, N.J.: Prentice-Hall Inc, 1979.

[6] Hassall J, Zaverick R. Acoustic Noise Measurements. 4th ed. Hovedg, Denmark: Bruel & Kjaer, 1979.

[7] Cheng DK. Analysis of Linear Systems. Menlo Park, CA: Addison-Wesley Publishing Co., Inc, 1961.

[8] American National Standards Institute, American National Specification for Sound Level Meters. ANSI S1.4 – 1971.

[9] Giardino DA, Seiber JP. Noise dosimeters – past, present and future. Sound and Vibration 1976; 10(10): 26–30.

[10] Parmeggiani L, ed. Encyclopedia of occupational health and safety, (2 Volumes). 3rd ed. International Labour Organization 1983; 593–6 and 1464–72.

[11] Hattis D, Ashford N, Heaton C, Katz J. Some considerations in choosing an occupational noise exposure regulation. United States Environmental Protection Agency, Washington, DC, 1976; 2–31.

[12] Burns W. Noise and Man. 2nd ed. London: John Murray, 1973.

[13] Dadson RS, King JH. A determination of the normal threshold of hearing and its relation to the standardization of audiometers. J. Laryng 1952; 66:366.

[14] Brown REC. Experimental studies on the reliability of audiometry. J Laryng 1948; 62:487.

[15] Hinchcliffe R. The threshold of hearing as a function of age. Acustica, 1959; 9:303.

[16] Glorig A, Davis H. Age, noise and hearing loss. Ann Otol 1961; 70:556.

[17] Ward DW, Glorig A. A case of firecracker-induced hearing loss. Laryngoscope 1961; 71:1590.

[18] Ewing A, Littler T. Auditory fatigue and adaptation. Br J Psych 1935; 25:284

[19] Taylor W, Pearson J, Mair A, Burns W. A Study of noise and hearing in jute weaving. J Am Acoust Soc 1965; 38:113

[20] Nixon JC, Glorig A. Noise-induced permanent threshold shift at 2000 cps and 4000 cps. J Am Acoust Soc 1961; 33:904

[21] Glorig A, Ward D, Nixon J. Damage risk criteria and noise-induced hearing loss. Arch of Otol 1961; 74:71.

[22] Eldredge D. The problems of criteria for noise exposure. In: Henderson D, Hamernik R, et al, eds. Effects of Noise on Hearing. New York: Raven Press, 1976. 5.

[23] American Academy of Otolaryngology. Guide for the evaluation of hearing handicap. Otolaryngol Head Neck Surg 1979; 87:539–51.

[24] Dickson E, Ewing A, Littler T. The effects of aeroplane noise on the auditory acuity of aviators. J Lar Otol 1959; 54:531.

[25] U.S. Air Force, Medical Services. Hazardous noise exposure. AF Reg. No. 160–3, Washington, DC, 1956.

[26] Ward D, Glorig A, Sklar D. Dependency of temporary threshold shift at 4 kc on intensity and time. J Am Acoust Soc 1958; 30(10):944.

[27] Kryter K, Ward D, Miller J, Eldredge H. Hazardous exposure to intermittent and steady-state noise. J Am Acoust Soc 1966; 39(3):451.

[28] Botsford J. Simple method for identifying acceptable noise exposures. J Am Acoust Soc 1967; 42(2):810.

[29] Robinson DW. Relations between hearing loss and noise exposure. In: Burns W, Robinson DW, eds. Hearing and Noise in Industry. Her Majesty's Stationery Office, London, 1970;100–51.

[30] Cohen A, Anticaglia J, Carpenter P. Temporary threshold shift in hearing from exposure to different noise spectra at equal dBA level. J Am Acoust Soc 1972; 51:503.

[31] American Industrial Hygiene Association. Guidelines for noise exposure control. J Am Ind Hyg Assoc 1967; 28:418.

[32] Ontario Government. Regulations for Industrial Establishments, Ontario Regulation 658/79, Statutes of Ontario, Chapter 83, 1978.

[33] Burns W, Robinson DW. Hearing and Noise in Industry. Her Majesty's Stationery Office, London, 1970.

[34] Ward D. Intermittence and the equal-energy theory. 107th meeting Acoust Soc Am. May 1984.

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Swipe Sampling for Polychlorinated Biphenyls

Summary

Contamination by PCBs of surfaces in workplaces can be estimated by swiping the surface according to established methods and analysing the swiping medium for the content of PCBs. The efficacy of two common methods was determined. It is shown that neither is sufficiently accurate or precise enough to measure surface contamination with confidence. However, one method is preferred over the other for estimating whether the contamination is low or high.

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Introduction

An estimation of the degree of surface contamination in workplaces is usually determined by following an established protocol to swipe a known area of the surface and to analyse the swipe samples for contaminants of interest. Traditionally, this has been used as an aid to determine the type of dust or material that may be present in a worksite and the adequacy of general housekeeping. Without doubt, swipe sampling has the potential for providing the occupational hygienist or physician with valuable additional information for assessing the overall exposure to polychlorinated biphenyls (PCBs). However, the lack of an established method for swipe samples and of criteria for surface contamination presents difficulties with interpretation of quantitative assessments.

It is generally recognized that PCBs are of very low volatility and, therefore, residual PCBs in contaminated work areas do not always create excessive airborne levels, but they persist in the environment for long periods of time. PCBs are known to be absorbed through the skin, and recently published data suggest this may be the principal route of entry.[1,2] Chloracne and liver injury are the most significant effects of exposures to PCBs.[3,4] Furthermore, although the epidemiological evidence for human cancer potential is inconclusive, experimental animal evidence suggests that PCBs may be carcinogenic.

Given the recognized health effects and the importance of skin absorption to overall exposure, there was clearly a need to investigate further how swipe sampling may be used to assess contamination of surfaces by PCBs and the effectiveness of clean-up procedures; therefore, the Occupational Health Laboratory initiated a small research project to examine swipe sampling. The general protocol was as follows:

i) six companies that had agreed to participate were visited, and two technicians were sent to each company;

ii) each technician took two swipe samples from up to 10 locations. The first sample was obtained by the

current method of the Occupational Health Laboratory (OHL) of the Ontario Ministry of Labour and the second was obtained by the method used by the Occupational Safety and Health Administration (OSHA) of the U.S.A. Thus four swipe samples were taken in close proximity at each location;

iii) one of the selected locations in each workplace was swiped twice so that a second set of four swipe samples was obtained from a previously swiped area;

iv) duplicate analyses by another laboratory technician were performed for a number of the submitted samples.

Method

Occupational Health Laboratory (OHL), Ontario

a) a gauze swab or dressing, pre-extracted with hexane, was used as the swiping medium;
b) clean glass jars were loaded with these gauze swabs or dressings;
c) each gauze swab or dressing was handled with clean tongs, moistened with hexane, and a known area (10 cm by 10 cm) was swiped;
d) the swiped gauze was placed inside a glass jar, which was then covered with aluminum foil before it was capped;
e) the tongs were rinsed with hexane after each swipe sample was taken;
f) one of the pre-extracted gauze swabs or dressings remained unhandled in its glass jar and was returned to the laboratory to be used as an analytical blank when required.

Occupational Safety and Health Administration (OSHA), U.S.A.

a) Whatman 41 or 42 paper filter was used as the swiping medium; pre-extraction with toluene was performed;
b) a group of clean vials was loaded with these paper filters;
c) each technician wore a pair of surgical gloves with a pair of clean, heavy rubber gloves over them; it was not necessary to change rubber gloves for each swipe sample taken. However, new rubber gloves and surgical gloves were worn for each company visited;
d) the prepared paper filter was withdrawn from the vial and held by the edge. A few drops of toluene from a

clean eyedropper were added to the centre of the filter;

e) by holding the edge of the moistened filter, a known surface area (10 cm by 10 cm) was gently swiped, care being taken that the filter paper did not disintegrate;

f) the filter, without contacting any other surface, was folded with the exposed side in and placed in a clean sample vial. The vial was capped and labelled;

g) at least one *blank* filter, treated in the same fashion, but *without* swiping, was submitted for each company visited.

Analyses of all samples were performed according to the Occupational Health Laboratory method: solvent extraction of the swipe sample medium with 20 mL hexane followed by gas chromatographic assay. The quantity of PCBs in the extract was determined by integrating the area under several selected peaks and calibrating against laboratory-prepared standards of the relevant PCB mixture. Where necessary, gas chromatography-mass spectroscopy was used to confirm the presence of PCBs. In total, 22 swipe sample extracts were analysed in duplicate to quantify analytical error.

Results and Discussion

A total of 176 swipe samples were taken, of which 24 were repeat swipes. Forty-four of the samples, which were all from one company (Company A), were very close to or below the detection limit and, where indicated, have not been included in the summary statistics. The swipe sample results are shown in Table 1. The duplicate swipe sample results are summarized in Table 2.

Table 1 **Swipe Sample Results**

	OHL Method		OSHA Method	
Company	**Tech 1**	**Tech 2**	**Tech 1**	**Tech 2**
A	2	1	<1	2
	1	1	<1	1
	1	1	1	1
	<1	<1	1	<1
	<1	<1	<1	<1
	* 1	2	<1	<1
	1	1	<1	1
	<1	1	<1	<1
	1	1	1	<1

Table 1 *(continued)*

Company		OHL Method Tech 1	OHL Method Tech 2	OSHA Method Tech 1	OSHA Method Tech 2
A		1	1	<1	<1
	*	<1	<1	<1	<1
B		272	520	8	20
	*	72	33	2	2
	*	19	22	8	1
		39	42	4	5
		74	4	3	1
C		127	384	<1	3
	*	155	96	26	12
	*	39	83	35	8
		38	18	15	10
		21	21	2	4
D	*	539	263	<1	5
	*	118	141	1	2
		243	182	28	10
		23	5	1	<1
		76	36	1	2
		174	527	42	31
		63	48	27	11
E		22	13	1	1
– areas swiped were		9	9	9	1
6″×6″ (225 cm²)		13	2	1	9
– tabulated values		53	98	84	58
have been		120	230	98	62
normalized to		*19,400	11,900	18,500	14,800
100 cm²	*	350	4,710	8,310	3,020
F		260	1,180	67	180
– areas swiped were		12,430	20,710	8,040	9,280
6″×6″ (225 cm²)		2,200	18,360	3,460	4,740
– tabulated values		2,910	2,750	1,330	1,220
have been		2,000	44	810	460
normalized to		1,150	1,830	600	540
100 cm²	*	6,080	28,290	6,060	2,650
	*	9,510	9,300	5,240	3,290
		6,750	3,160	710	490

All results are in micrograms per 100 cm².

* The two lines of results with asterisks are duplicate swipes of the same area.

Table 2 **Results of Repeat Swipe Samples**

Occupational Health Laboratory Method

Company	Technician 1 First Swipe	Technician 1 Second Swipe	Technician 1 (Second/First)%	Technician 2 First Swipe	Technician 2 Second Swipe	Technician 2 (Second/First)%
A	1	<1	–	2	<1	–
B	72	19	26.4	33	22	66.7
C	155	39	25.2	96	83	86.4
D	539	118	21.9	263	141	53.6
E	19,400	350	1.8	11,900	4,710	39.7
F	6,080	9,510	157.0	28,290	9,300	33.0

Occupational Safety and Health Administration Method

A	<1	<1	–	<1	<1	–
B	2	8	400	2	1	50
C	26	35	135	12	8	66
D	1	1	100	5	2	40
E	18,500	8,310	44.9	14,800	3,020	20.4
F	6,060	5,240	86.5	2,650	3,290	124

Results are in micrograms per 100 cm^2.

The replicate analytical results are shown in Table 3. They show that, on average, there was a 19 per cent difference, but the coefficient of variation (CV) was 101.6 per cent. The higher average differences and wider range (0 per cent, to 76.9 per cent) reflect, in part, the cumulative error that arises in selecting and measuring the many peaks seen in a gas chromatographic analysis of PCBs.

The Occupational Health Laboratory method gave results higher than the Occupational Safety and Health Administration method (excluding Company A) in 59 of 66 (89.4 per cent) comparisons (Table 1), and the differences are statistically significant ($t = 2.28$, $p = 0.026$; paired t-test). The former method permits some scrubbing during sampling; therefore, it can be expected to yield higher results.

If it is assumed that the PCB contamination is relatively uniform in each plant, then each swipe is an estimate of the general surface contamination in the plant. Within the five plants with measurable levels being investigated, the distribution of values about the mean, measured by the coefficient of variation (also known as the relative standard deviation), is an estimate of the precision of the method (Table 4).

Table 3 Results of Repeat Analyses

Company	Sample No.*	Result 1	Result 2	% Difference**
A	3A (OHL)	0.89	0.87	2.2
	(OSHA)	0.70	0.63	10.1
	3B (OHL)	0.53	0.68	22.1
	(OSHA)	0.53	0.48	9.4
B	3A (OHL)	19	19	0
	(OSHA)	8	6	25.0
	3B (OHL)	22	31	29.0
	(OSHA)	1	1	0
C	3A (OHL)	39	9	76.9
	(OSHA)	35	16	54.3
D	6A (OHL)	174	102	41.4
	(OSHA)	42	41	2.4
	6B (OHL)	527	548	3.8
	(OSHA)	31	28	9.7
E	6A (OHL)	43,700	46,700	6.4
	(OSHA)	41,600	48,800	14.8
	6B (OHL)	26,700	36,200	26.2
	(OSHA)	33,300	51,800	35.7
F	4A (OHL)	6,540	6,950	5.9
	(OSHA)	2,990	2,500	16.4
	4B (OHL)	6,190	6,700	7.6
	(OSHA)	2,750	2,210	19.6

Average 19%
(CV = 101.6%)

* The numeral refers to the line entry position in Table 1; the letter A refers to Technician 1, and B, to Technician 2. For Companies E and F, the numbers shown are analytical results before normalization to 100 cm^2.

** Expressed as a percentage of the larger value.

Table 4 Coefficients of Variation of Swipe Sample Results for Companies Listed

		COMPANY				
CV		B	C	D	E	F
OHL Method	%	149	113	99	221	112
OSHA Method	%	106	96	122	193	104

In four of the five companies the Occupational Safety and Health Administration method gave lower coefficients of variation (CV), suggesting that this method is modestly more precise. However, the degree of difference is not sufficient, in a small study of this type, to express confidence in one method over the other.

Without differentiating between the two methods, and excluding Company A, the difference in values obtained by two technicians who were sampling adjacent areas at one location in a plant averaged 46.8 per cent and ranged from 0 per cent to 98 per cent (expressed as a percentage of the greater of the two compared values in Table 1). This is far greater than the 10 per cent to 20 per cent difference that side-by-side air samples would generally be expected to produce. There was no systematic bias in that no technician was seen to produce results consistently higher than the other ($t = 0.86$, $p = 0.39$; paired t-test).

The repeat swipe samples over areas previously sampled (Table 2) indicated that, for the Occupational Safety and Health Administration method, a further 20 per cent to 135 per cent (average 74 per cent) of the amount of PCBs seen in the first sample was seen in the second (excluding Company A). For the Occupational Health Laboratory method, the range is 2 per cent to 157 per cent (average 51 per cent). Therefore, neither method has a collection efficiency close to unity, which is required when selecting a preferred sampling method.

There was no typical ambient surface contamination level discernible in this study. However, it is apparent that three of the five plants (B, C, D) have relatively low levels, with only three of 34 samples by the Occupational Health Laboratory method showing results higher than 500 ug/100 cm^2. Even within one of the two plants with high readings (E), lower values (less than 230 ug/100 cm^2) are seen in 10 of 14 areas. This suggests that there may be areas either lightly or heavily contaminated.

Skin absorption of PCBs is known to occur and, indeed, is highlighted by the American Conference of Governmental Industrial Hygienists (ACGIH)[5], but the degree of absorption is not yet established, and the relative contribution of skin absorption to body burden (i.e. total absorbed dose) is unknown. The ACGIH[6] states:

> ' ''Skin'' Notation. Listed substances followed by the designation 'Skin' refer to the potential contribution to the overall exposure by the cutaneous route including mucous membranes and eye, either by airborne, or more particularly, *by direct contact with the substance. Vehicles can alter skin absorption.*

'Little quantitative data are available describing absorption of vapours and gases through the skin. *The rate of absorption is a function of the concentration to which the skin is exposed.*

'*Biological monitoring should be considered* to determine the relative contribution of dermal exposure to the total dose.

'This attention-calling designation is intended to *suggest* appropriate measures for the prevention of cutaneous absorption so that the threshold limit is not invalidated.'

(emphasis added)

It can be argued that there is no credible surface contamination standard, no reliable method to determine the extent of surface contamination and, in cases where a clean-up of surfaces is attempted, no adequate measure of an acceptable level of contamination.

However, the Occupational Health Laboratory method of sampling and analysis can determine with relative confidence whether the contamination is low or high. Judging from these results, it seems that 1,000 ug/ 100 cm^2 may be a working guideline to distinguish high and low levels. Moreover, the Occupational Health Laboratory method is preferable since it swipes more PCBs from the surface than the Occupational Safety and Health Administration method.

Conclusion

Since analyses for PCBs are relatively free from interferences and false-positive results, swipe sampling can be used to indicate the presence or absence of PCBs within the analytical errors, and, furthermore, is adequate to determine whether PCB contamination is relatively low or high. The Occupational Health Laboratory method is preferred.

When evaluating a work situation for PCB contamination, several factors must be considered:

i) high or low surface contamination;
ii) degree of skin contact with contaminated surfaces;
iii) frequency and length of time in contact;
iv) air levels of PCBs in the area.

Occupational health professionals, when conducting an investigation, should evaluate all these factors before making recommendations with respect to clean-up and work practices.

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Résumé

Il est possible d'estimer la contamination, par le BPC, des surfaces dans les lieux de travail en essuyant la surface à étudier selon des méthodes déterminées et en analysant ensuite la teneur en BPC de l'objet utilisé pour essuyer ladite surface. On a pu ainsi déterminer l'efficacité de deux méthodes couramment utilisées. On a constaté que ni l'une ni l'autre n'est suffisamment rigoureuse ou précise pour permettre de mesurer avec certitude le degré de contamination de la surface étudiée. Toutefois, l'une de ces méthodes a la préférence lorsqu'il s'agit de déterminer si la contamination est faible ou élevée.

References

[1] NIOSH criteria for a recommended standard . . . Occupational exposure to polychlorinated biphenyls. U.S. Department of Health, Education and Welfare, 1977.

[2] WHO. Polychlorinated biphenyls & terphenyls. Environmental health criteria. Geneva, 1976.

[3] Maroni M, Colombi A, Cantoni S, Ferioli E, Foa V. Occupational exposure to polychlorinated biphenyls in electrical workers. I. Environmental and blood polychlorinated biphenyls concentrations. Br J Ind Med 1981;38:49–54.

[4] Maroni M, Colombi A, Cantoni S, Ferioli E, Foa V. Occupational exposure to polychlorinated biphenyls in electrical workers. II. Health effects. Br J Ind Med 1981;38:55–60.

[5] American Conference of Governmental Industrial Hygienists. Threshold limit values for chemical substances and physical agents in the work environment and biological exposure indices with intended changes for 1984–85:13.

[6] Ibid: 6.

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A Quality Grading Code for Spirometry

Summary

A grading code is described for summarizing the quality of tracings taken in forced expiratory spirometry manoeuvres. The code is analogous to the grading of the profusion of small opacities seen on chest X-rays of the pneumoconioses. It divides tracings into four major categories of quality with reference to adherence to American Thoracic Society standard criteria for spirometry. A set of minor categories on a 12-point scale is also described.

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A Need for Critical Evaluation of Tracings

While the American Thoracic Society (ATS) criteria for performing pulmonary function tests[1] have brought standardization to spirometric screening at the source of the test, the recipient of a calculated report often has no way of estimating the quality of effort or degree of adherence to standard criteria. Usually, original tracings are filed at the laboratory, where the large-scale production of copies can produce logistic problems as well as prove expensive. In a hospital setting, the interpreting physician has traditionally noted irregularities by direct inspection of the tracings, but with more frequent computerized reporting the quality evaluation step is sometimes bypassed or at least not recorded. Furthermore, in a large occupational screening program it may be efficient to delegate the basic evaluation of most tracings to specially trained technologists, with the physician making additional assessments only on the more difficult cases. In these situations, a reproducible, clinically relevant and easily remembered grading notation would ease quality control procedures and could also be incorporated into a computer data-base for use in a continuing performance audit.

The Ontario Ministry of Labour Occupational Health Branch Chest Clinic adopted the ATS criteria for its mobile screening service shortly after their publication and has actively taught the system in conjunction with instructors from the Canadian Society of Pulmonary and Cardiovascular Technologists in the semi-annual University of Toronto School of Continuing Studies course 'Pulmonary Function Testing in Industry'. The result has been an overall rise in tracing quality within the area of influence and, in addition, physicians who receive the reports have become more critical in demanding tests of good quality. There have been requests for original tracings from time to time, suggesting that no longer are lists of numerical values accepted without question, especially if results are unexpected or serial trends indicate unusual rates of change.

The situation in which the chest clinic receives tracings

for interpretation from various external sources also poses a quality control problem. Since standardization is not always adequate or uniform, it would be desirable to report the degree of confidence placed on the calculated results.

This rise of interest is commendable and could be aided by routinely using a grading notation. Surprisingly, no such code for estimating tracing quality appears to have been published. For these reasons, the ministry's chest clinic developed a spirometric quality control notation and has, for the past year, reported it routinely while making a number of intercurrent adjustments as experience developed.

Desirable Characteristics in a Code

The code should define to what general degree the ATS criteria were met as well as indicate, for clinical purposes, the degree of confidence that should be ascribed to the calculated results. A useful grading scheme must be easy both to remember and to understand intuitively. It should also accurately differentiate between important shortcomings and provide good inter- and intra-observer reproducibility as well as use computer and paper space economically, and require minimal teaching time. Some recognizable tie to any already existing quality control notation could be an advantage as long as confusion did not arise. An encyclopaedic listing of all pitfalls, however, would be beyond its scope, and a request for this type of more complete information might still require a more detailed report.

General Description of the Grading Notation

A useful model was found in the International Labour Office (ILO) Classification of Radiographs of the Pneumoconioses[2]. This contains a coding of the profusion of small, rounded or irregular opacities, which are described on a four-point scale of major categories: 0, 1, 2, 3. Since there is often doubt about whether a film should be classified in one or another of adjacent major categories, the code has been expanded to a 12-point format including minor categories[3]. Thus, a film that is eventually coded as Category 2 would be coded as '2/1' if, in the process of deliberation, Category 1 had been seriously considered as an alternative. Similarly, a film that was finally called normal would be labelled '0/1' if, in deliberations, Category 1 was seriously considered.

Analogously, the spirometric grading describes four major categories: A, B, C and D, which represent progressively deteriorating quality of tracing. The grader should first try to determine whether a tracing falls into

one of the four major categories by referring to the definitions below and also to the four reference tracings. If there is no difficulty with this, and, for example, Grade A is chosen, the tracing is labelled A/A to indicate that the major category was 'A' (above the slash) and that there was no doubt about it being an 'A' (entered below the slash).

Experience has, however, shown that it is sometimes difficult and time-consuming to make grading decisions on only the four major categories. It has been easier, both in the radiologic readings and in our own experience with the present code, to be able to express doubts and borderline situations by the expanded 12-point scale. This was also found to be true in spirometric work: Rather than spend time on finally deciding whether a tracing is A or B, it is easier to state that it is a 'B/A', indicating that when all was done, Category B was selected, but there had been significant doubt whether, in fact, A should have been chosen. Similarly, a Category C about which there had been no serious doubt, would be labelled C/C. If a grade even better than 'A' could be conceived, it would be called A/- since there is no letter preceding A; similarly, if a tracing were thought to be worse than a D, it would be labelled D/+ since no additional letter has been allotted in the scale. The extremes were, thus, called A/- and D/+ respectively, again drawing the analogy from the ILO radiographic classification.

In summary, all the possible combinations could be represented in a Table:

A/-	A/A	A/B
B/A	B/B	B/C
C/B	C/C	C/D
D/C	D/D	D/+

The first letter of the code always indicates the ultimate choice, and the last letter shows the alternative adjacent category that had been seriously considered but rejected. If no doubt exists, the first letter is simply repeated under the slash.

Definitions

The following definitions were evolved after a series of re-evaluations based on trial and error. They cover all of the tracing pitfalls met in practice to this point and follow a progression that is intended to be compatible with clinical grading needs.

Category A:	Very good reproducibility *and* all ATS criteria have been met.
Category B:	At least one parameter (FVC or FEV_1) shows evidence of less than maximal effort *or* one ATS criterion was not met.
Category C:	No evidence that maximal effort was obtained in any parameter *or* at least two ATS criteria have not been met.
Category D:	Definitely submaximal efforts. Values should not be used as a basis for statistical trend calculations.

The chest clinic computer program has been adjusted to produce a phrase for each of the categories derived from the appropriate definitions above. Because of previously committed program space, the slash (/) cannot be printed at the present time, and on ministry reports a B/A grade would appear as BA.

Reference Tracings

A set of four tracings for each of the major categories A, B, C and D was found helpful both as a teaching aid and as a quick visual reference in using the code (Figure 1). It is, however, difficult to represent adequately the many variations that may be found in spirometry, both artefactual and physiologic. For this reason, the stated definitions are to take precedence in cases of doubt. It is interesting to note that earlier versions of the ILO code also promoted definitions in preference to illustrative films, and only recently has there been a change so that reference X-rays now outweigh the definitions. It is possible that, with further development, the spirometric code, too, will follow a similar evolution since input from users may lead to improved definitions and more definitive reference tracings.

Experience in Use

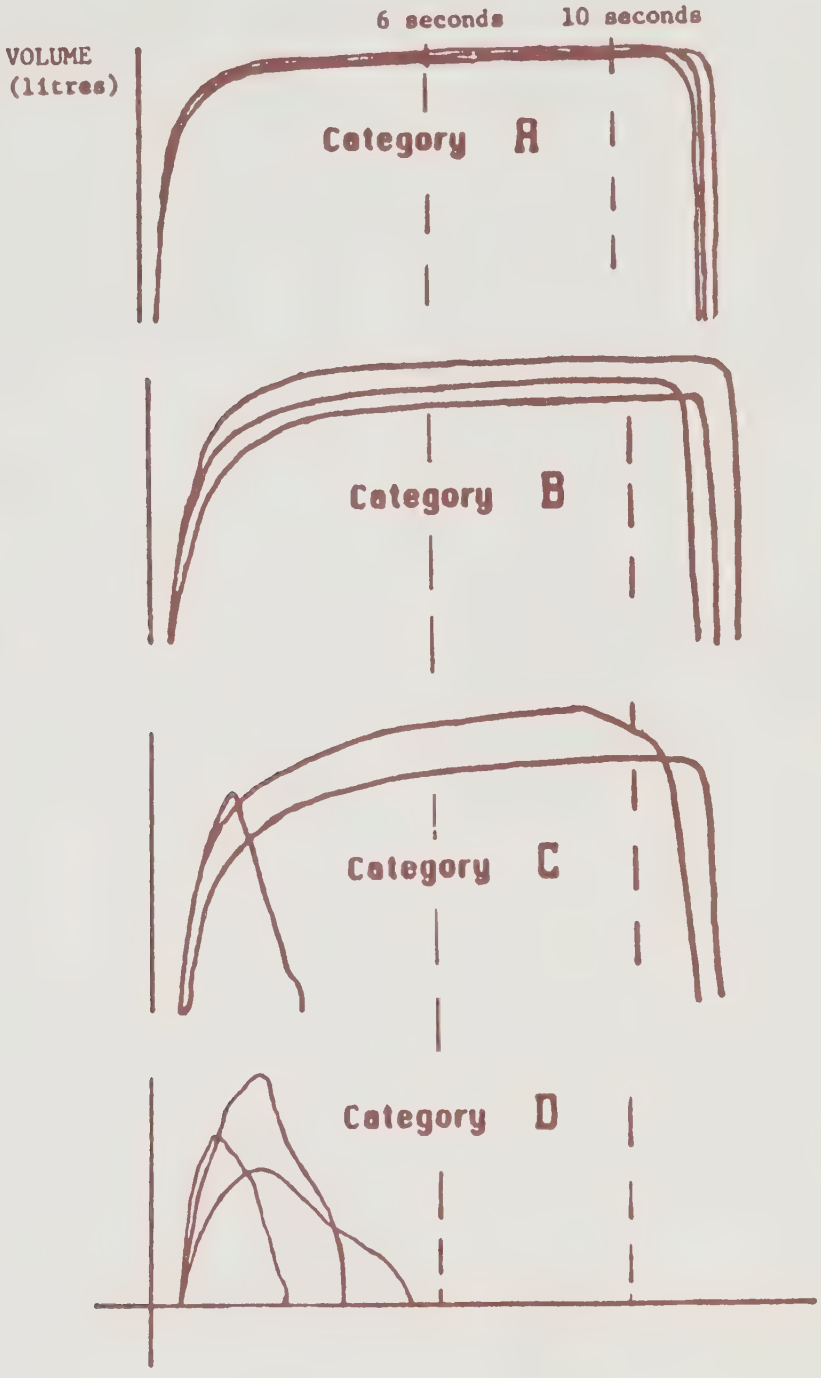
In routine test reports the code is placed next to the test results. Several benefits were found during its use:

1. It allowed technical staff to convey to medical personnel an overall summary of the many individual factors that together make up an acceptable tracing.

2. Specific quality statements were produced in the medical report in order to aid valid interpretation.

3. The computer data base could now be selectively

Figure 1 **Reference Tracings for Spirometric Grading**



searched for tracings of a specific quality when doing statistical studies or administrative audits.

4. The quality of testing could be monitored frequently in order to improve program delivery.

5. The time needed to establish a grade was found to be very short, and was further diminished by using the 12-point scale.

Teaching and Reproducibility

The system has been taught to physicians, trained pulmonary function technologists and experienced clerical staff as well as to staff untrained in recognizing spirometric tracings or graphs. The principles of coding can be taught in a few minutes to all these groups, but it is clear that some background with scientific graphs is helpful to the user, if only to instil a sense of confidence. Studies with a standard batch of tracings are now underway to determine the inter- and intra-observer variation. Initial results suggest that some 70 per cent of tracings are coded identically by an experienced reader, with the remainder diverging by one minor category. There were no discrepancies beyond that range. Early findings also show that the general reading level of both experienced and inexperienced readers is about the same, but that the inexperienced readers have a greater variance from the mean.

Limitations of the Code

The many different pitfalls in spirometry would make a detailed quality report cumbersome for routine use. The current approach represents an attempt to offer simplicity, but some limitations must be accepted as a compromise. One difficulty lies in defining, in Category B, which of the two major parameters is inadequate – the FVC or the FEV_1. The easiest solution, to include subscripts in the code, was tried in one of the preliminary versions, but was eventually rejected for the sake of simplicity. The temptation to use additional subscripts grew, and this led to difficulties in remembering the code or in always having its key available. It remains to be seen whether this failing is of clinical concern or whether physicians can detect from pattern recognition which of the two measurements is deficient. Another limitation for some interpreters may stem from unfamiliarity with the ILO radiographic code, which otherwise provides an easy memory aid to those accustomed to coding chest X-rays.

The amount of inter- and intra-observer variation will need additional study with larger numbers of users, and the degree to which physicians will benefit from an overall quality code should also be documented after some time in use.

Conclusion

Screening spirometry, performed as part of an occupational health program, can be continuously monitored for quality of technique on all tracings, and each test can be reported for adherence to standard criteria and quality of effort. This flexible grading system

can provide clinically relevant information without significant time loss on the part of either the grader or the recipient. It is hoped that an increased awareness of quality will stimulate laboratories involved in occupational pulmonary function screening to maintain and demonstrate the existence of a technically satisfactory program.

Résumé

Ce document inclut la description d'un code de classification destiné à résumer la qualité des tracés relevés au cours d'exercices spirométriques d'expiration forcée. Ce code est semblable à celui utilisé pour la classification des nombreuses petites taches opaques décelées sur les radiograhies des pneumoconioses. Il répartit les tracés dans quatre principales catégories de qualité, avec des références sur l'adhésion aux normes établies par l'American Thoracic Society pour la spirométrie. Ce document décrit également un ensemble de catégories mineures selon une échelle de 12 degrés.

References

[1] American Thoracic Society Statement – Snowbird workshop on standardization of spirometry. Am Rev Respir Dis 1979; 119:831–38.

[2] International Labour Office: Guidelines for the use of ILO international classification of radiographs of the pneumoconioses. Rev ed. 1980. International Labour Office Occupational Safety and Health Series No. 22. Published by the International Labour Office, Geneva, Switzerland.

[3] Liddell FDK. An experiment in film reading. Br J Ind Med 1963; 20:300–12

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Health Effects of Occupational Exposure to Formaldehyde*

Summary

This report reviews the salient features of the physical, chemical and biological properties of formaldehyde that determine human and animal response to this compound. On the basis of these considerations, coupled with a succinct analysis of published findings and ongoing research, conclusions are drawn and recommendations are made concerning the health effects of formaldehyde.

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Basic Features of Formaldehyde

Formaldehyde is an endogenous metabolite, formed and utilized within the body as part of the organism's essential metabolic machinery. For this reason, and by virtue of its chemical reactivity, formaldehyde is bound to glutathione as a hemiacetal in order to protect the cell from its cytotoxic action. The cellular level of glutathione constitutes the first line of defence; only when that level is seriously depleted does the cytotoxic action of formaldehyde come into play.

Another important property of formaldehyde gas is its high solubility in water (55g/100g water at 25°C; compared to HC1, 67.3g/100g at 30°C). Hence, formaldehyde dissolves almost instantaneously at the point of impact on the surfaces of mucous membranes in the upper airways: the anterior part of the respiratory epithelium in obligatory nose-breathers such as the rat, as well as the buccal cavity and upper respiratory tract of humans. Only exposure to very high levels of formaldehyde permits it to penetrate to the lower respiratory tract.

Once formaldehyde has dissolved, it tends to react with mucus of the mucociliary apparatus (see below). Any remaining free formaldehyde passes into cells lining the upper respiratory tract, where it is acted upon by a well-developed biotransformation system for metabolizing formaldehyde to formate and carbon dioxide as well as being utilized in the body's one-carbon pool. So rapid and complete is the process that, under all but the most extreme conditions of exposure, inhalation of formaldehyde causes no detectable increase in the background level of circulating formaldehyde in the blood, nor does intact formaldehyde (as distinct from its metabolic products) reach distant organs such as the liver, bone marrow or brain (Casanova-Schmitz *et al*, 1984). The carbon moiety of formaldehyde is widely distributed within the one-carbon pool and metabolically incorporated into a variety of body components.

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Formaldehyde is a 'sensory irritant', a term applied to inhaled chemical agents that stimulate trigeminal nerve endings in the nasal mucosa. A burning sensation is elicited in the nasal passages, accompanied by a concentration-dependent inhibition of respiration. Plotting concentration-response regression lines for sensory irritants permits calculation of the RD50, the concentration that causes a 50 per cent reduction in respiration rate of an animal. Thus the RD50 for formaldehyde in Swiss-Webster mice is 3.1 ppm (indicating high potency), and for hydrogen chloride, 309 ppm.

The role of the respiratory mucociliary clearance mechanism (RMCM) as a defence against formaldehyde is important for several reasons. RMCM acts as a barrier to protect against penetration of formaldehyde to underlying structures, as mentioned above. Reaction with formaldehyde can impair the normal rate and pattern of flow of mucus in the nasal cavity. At 15 ppm formaldehyde causes extensive inhibition of nasal mucociliary function. Thus there is evidence that the RMCM is overwhelmed at high levels of formaldehyde exposure. It is at such levels that the cytotoxicity of formaldehyde becomes manifest, resulting in exfoliation, erosion, ulceration and necrosis of the anterior respiratory epithelium in the nasal cavity of the rat. The familiar pathophysiological cycle of injury, repair, hyperplasia and dysplasia of the epithelium is thereby instituted.

The epithelial repair process involves cell proliferation and DNA replication, the extent of which can be followed by using tritiated thymidine as marker. Studies of formaldehyde concentration (C) $\times$ duration of exposure (t) have shown conclusively that, for a given value of C $\times$ t ppm-hours, high concentration rather than duration of exposure is the factor that determines high DNA replication (Swenberg *et al*, 1983). For example, exposure to 12 ppm for 3 hours a day over a period of 3 days (C $\times$ t = 108 ppm-hr) caused a 17-fold increase in cell replication, whereas with 3 ppm for 12 hours a day over 3 days (C $\times$ t = 108 ppm-hr), the increase was only threefold. By the 10th day of exposure, only the 12 ppm regimen continued to show increased cell replication.

The Animal Evidence

This section will be limited to the information forthcoming from long-term inhalation studies in laboratory animals. In rats exposed to 14.3, 5.6 and 2 ppm formaldehyde gas for 2 years, approximately

50 per cent developed nasal squamous cell carcinomas at 14.3 ppm, only 1 per cent at 5.6 ppm, and no tumours developed at 2 ppm or in the air controls. Studies in mice yielded either 1 or 3.3 per cent tumours at 14.3 ppm, depending on the basis of calculation (Swenberg *et al*, 1980; Kerns *et al*, 1983). Experiments on neoplasia in hamsters have proved negative. In these studies (Dalby, 1982), male Syrian golden hamsters were exposed to 10 ppm formaldehyde 5 hours a day, 5 days a week for lifetime. No tumours were observed in the nasal turbinates or other respiratory tract tissues. The results in rats have been duplicated in two studies, using exposure to approximately 14 ppm formaldehyde, with or without approximately 10 ppm hydrochloric acid gas (HC1) (Albert *et al*, 1982). The fact that HC1 alone did not produce nasal tumours was claimed as evidence that the 'irritant' action of formaldehyde was not a prerequisite for tumour development. If this claim alluded to sensory irritation, then – as mentioned above – HC1 (RD50 = 309 ppm) could not be compared with formaldehyde (RD50 = 3.1 ppm). If this claim referred to development of tissue damage and increased cell replication, 10 ppm HC1 elicits no such effect in the rat.

The most appropriate data for risk assessment are the results of the first rat study, in which the yield of tumours were: 50 per cent at 14.3 ppm, 1 per cent at 5.6 ppm and 0 per cent at 2 and 0 ppm. The non-linearity of this dose-response curve becomes even more evident when, rather than considering the ambient levels of formaldehyde, account is taken of the biologically effective or 'delivered' dose of formaldehyde (i.e. the amount reaching the target DNA in the nasal mucosa) (Casanova-Schmitz *et al*, 1984; Casanova-Schmitz and Heck, 1985). In these studies the delivered dose of covalently-bound formaldehyde, as distinct from metabolically-incorporated carbon originally derived from inhaled formaldehyde, was accurately measured. Use of these target dose data leads to an even steeper – more strikingly non-linear – dose-response curve for the rat data under consideration (Starr and Buck, 1984). As stressed by Hoel *et al* (1983), such non-linearity has to be taken into account in low-dose risk extrapolations. Calculating exposure on the basis of the biologically-effective dose, rather than the ambient air concentration, leads to much lower maximum likelihood estimates of risk, no matter which mathematical model is used.

The mathematical calculations are, of course, based on very limited data; they cannot encompass the totality of biological evidence on formaldehyde. This evidence does

not suggest the usual behaviour of a chemical carcinogen. At worst, formaldehyde may be regarded as a weak carcinogen in the rat, its capacity to produce neoplasia being dependent on exposure to levels that cause acute tissue degeneration, necrosis, inflammation and cell replication as a consequence of this tissue injury (IARC, 1982). The hamster, in which no tissue injury is elicited, does not develop tumours under similar conditions.

Genetic Toxicity

The genetic toxicity of formaldehyde has been studied extensively in both *in vitro* and *in vivo* test systems. It is generally acknowledged that formaldehyde can induce genetic alterations in *in vitro* test systems for genotoxicity. It has been established, for example, that formaldehyde induces single strand breaks in DNA, protein – DNA crosslinks, sister chromatid exchanges in CHO cells and chromosome aberrations, the latter results being somewhat equivocal. Results of tests in bacterial systems, yeasts and fungi on the whole are positive, though some negative responses have been reported. Positive results also have been reported in human cell lines in culture. Overall, these *in vitro* studies suggest that formaldehyde is a weak mutagen; responses generally did not exceed 10 times background.

The results of *in vivo* studies of genetic toxicity are equivocal, and positive results, when obtained, were generally marginal and occurred only at very high exposure rates (25 ppm). No consistent positive results have been reported in dominant lethal studies in rats, and formaldehyde failed to induce micronuclei or chromosome aberrations *in vivo*. A small increase in sister chromatid exchanges was noted in the bone marrow of mice exposed to formaldehyde at airborne concentrations in excess of 25 ppm, but no dose-response information is available, and apparently this study suffered from numerous technical flaws. No chromosome aberrations or increased frequency of sister chromatid exchanges were noted in pathology staff occupationally exposed to formaldehyde at concentrations of up to 7 ppm (Thomson *et al*, 1984). A well-conducted mouse spot-test was negative.

In general, the results of *in vivo* genetic toxicity studies do not support the results seen *in vitro*, a finding which may be explained, in part, by studies on the metabolism of formaldehyde. It is clear that at low exposures (e.g. 1 ppm or less) formaldehyde is rapidly assimilated into the metabolic pool or bound to tissue proteins and other macromolecules, thus reducing the amount of

formaldehyde potentially available to interact with genetic material. This conclusion is supported by the results of studies in rats exposed to airborne concentrations of up to 14.3 ppm formaldehyde which failed to produce any detectable covalent binding in bone marrow cells (Casanova-Schmitz *et al*, 1984). These studies also tend to cast further doubt on the significance of the weakly positive sister chromatid exchange studies in mice. However, the results of these studies would not preclude the possibility that formaldehyde could induce mutations in epithelial cells of the nasal mucosa directly, especially at high airborne exposure levels. Likewise, one cannot rule out the possibility that formaldehyde may act in a promotional role; however, in well-validated promotional assays such as C3H/10T1/2 cells and mouse skin, it has shown only weak or equivocal activity. In the same cell system, formaldehyde proved to be a weak initiator, capable of bringing about neoplastic transformation at high concentrations.

The assessment of the significance of the genetic toxicity studies in relation to formaldehyde-induced nasal tumours in rodents must take into consideration the known biochemical and functional effects of formaldehyde in the nasal mucosa. Available studies (Casanova-Schmitz and Heck, 1985) indicate that no measurable covalent binding of formaldehyde to DNA occurs at or below 0.9 ppm. This observation is supported by studies which demonstrate no significant incorporation of radio-labelled thymidine into the DNA of nasal mucosal cells at levels below approximately 2 ppm following repeated exposures (Starr *et al*, 1984). Moreover, the structure and function of the nasal epithelium and ciliary apparatus as observed by light and electron microscopy was not affected at a concentration of 1 ppm in monkeys, rats or hamsters (Rusch *et al*, 1983). These observations support the thesis that formaldehyde probably induces no significant genetic toxicity below one ppm. Overall, the effects appear to demonstrate a practical threshold. On the other hand, short-term animal studies have clearly demonstrated that, at exposure levels of 6 ppm and greater, significant histopathologic damage is present in the nasal mucosa which is accompanied by a substantive degree of covalent binding of formaldehyde to DNA. DNA repair (as measured by thymidine incorporation) is significantly increased at exposure concentrations of 6 ppm and higher. It is possible that at high concentrations (6 – 15 ppm) formaldehyde does induce genetic damage which may play a role, along with other factors, in tumour development.

Epidemiology and Other Human Studies

There have been a minimum of 15 published epidemiological studies up to and including 1983 and at least four reports in 1984. Nine of the studies were on mortality from various types of cancers and other diseases in pathologists, anatomists and embalmers, and the remaining on industrial workers.

Despite the number of studies, the numbers of individuals and deaths observed have been relatively small with a corresponding decrease in accuracy and reliability concerning any definitive conclusions. At least one larger study is in progress in the U.S.A. This is to be completed in 1985.

Certain patterns appear to be evident to date. One obvious pattern is the absence of any indication that individuals exposed to formaldehyde (as well as to other chemicals simultaneously) have shown an increased risk of developing any neoplasms of the upper or lower respiratory tract, including the nasal mucosa and bronchi. This pattern was seen in all studies reported. This negative trend seems also to be present for chronic respiratory disease, especially emphysema.

Another pattern that emerges is the absence of a reproducible increase in incidence of any single type of cancer in all the groups exposed to formaldehyde occupationally. Although some individual studies do show increased standardized mortality ratios for one or more types of cancers or other chronic diseases, the patterns are not reproducible from study to study. However, pathologists, anatomists and embalmers do shown an elevation in incidence of brain gliomas in some of the studies (Harrington and Oakes, 1984; Walrath and Fraumeni, 1984; Walrath and Fraumeni, 1983; Levine *et al*, 1983). Of the 26 brain tumours observed in these four studies, 21 were primary, two were metastatic, and three were of unknown histologic type. It is probable that these incidences would have been decreased if more accurate histological diagnosis had been used.

Some of the available studies also showed increases of lesser magnitude for neoplasms of the colon, prostate, kidney, lymphopoetic system and leukemia, but the numbers are small and the findings are not uniform. An additional finding in embalmers only was an increased incidence of cirrhosis of the liver.

In contrast to the findings in professional groups, industrial workers exposed to formaldehyde did not show this pattern of tumours. No increased incidence of brain tumours was seen in any of the studies reported (Acheson *et al*, 1984). It should be pointed out that professional

groups have been shown to receive a more accurate autopsy diagnosis than the average industrial worker (O'Berg, 1985; Pell *et al*, 1978). This confounding variable probably accounts, in large part, for the apparent difference in brain tumour rates between professional and industrial workers. As has been emphasized many times, the assessment of validity of the studies must include some information on extent and degree of exposure to formaldehyde and to other chemicals and on the duration of exposure. A minimum exposure period of 20 years or so would seem to be indicated, as judged by the long duration of the carcinogenic process in rats and the experience with other hazards in humans.

Further doubt is cast on the suggestion that formaldehyde may be associated with the development of brain tumours in humans when it is recognized that, at exposure levels of 1.9 ppm for 40 minutes, no detectable elevation of formaldehyde blood levels was observed in humans (Heck *et al*, 1985). In rats, exposure to concentrations up to 14 ppm for 2 hours did not result in any detectable increase in blood levels of formaldehyde (Heck *et al*, 1985). Based on this data it is highly unlikely that formaldehyde *per se* could cause brain tumours in humans.

There have been few studies that have specifically addressed the effects of formaldehyde on nasal structure and function in humans. Andersen and Molhave (1983) studied the effect of formaldehyde on mucus flow, nasal discomfort and respiratory function in human volunteers. In this study, 16 healthy male and female students were exposed to 0, 0.3, 0.5, 1.0 and 2.0 mg/m^3 formaldehyde for 1 to 3 and 4 to 5 hours, using a latin square experimental design. The authors concluded that formaldehyde reduced nasal mucus flow even at the lowest exposure level. The conclusions of the authors warrant close examination. In the first instance, the apparent reduction in mucus flow, while statistically significant within the context of the experimental design employed, represented only a 20 per cent reduction overall. In addition, the effects noted were not dose and/or time related. Furthermore, the effects were not what would be expected to occur in humans based upon extensive studies in animal models. These studies (Morgan *et al*, 1984) clearly demonstrate a biphasic response of mucus flow to formaldehyde exposure. Low level exposure (0.28 – 1.52 ppm) resulted in increased mucus flow, while higher levels (4.75 – 9.44 ppm) resulted in muco- and ciliastasis following an initial and transient increase. These observations coupled with the

findings of Andersen and Molhave that exposure to air alone resulted in an apparent reduction in mucus flow casts doubt on the significance of the human studies.

Critical Considerations Pertaining to Formaldehyde

Were formaldehyde a typical carcinogen, such as many polycyclic aromatic hydrocarbons, nitroso compounds or aromatic amines, the animal data would give sufficient guidance to consider it as one. However, it must be realized that formaldehyde is a normal constituent of the mammalian organism. Blood levels in unexposed humans are reported to be 2.61 mg per litre (Heck *et al*, 1985). This would represent a total body pool of approximately 140 mg of formaldehyde. Given the size of the formaldehyde pool, an exposure of 0.82 mg/m^3 (1 ppm) of formaldehyde would result in an addition to the blood pool of the average worker of approximately 0.08 per cent per minute assuming all of the formaldehyde reaches the blood. In reality this figure would be much lower due to the rapid metabolism of formaldehyde in the respiratory and buccal mucosa and the short half-life (1.5 minutes) of formaldehyde in blood (McMartin *et al*, 1977; 1979). This places formaldehyde in a totally different position with respect to the dose/risk relationship for all diseases other than those at the sites of initial interaction or entry. Tolerable levels of exposure will not significantly change the pool size so as to alter, quantitatively or qualitatively, the patterns of metabolism and reactivity of formaldehyde. Omission of such considerations is quite unjustified in *any* risk assessment of formaldehyde at lower dosage, i.e. at dosages that are well below those which produce pathological changes at sites of exposure.

We are of the opinion that at relatively larger doses, as shown by the C $\times$ t studies, formaldehyde should be considered like any other putative carcinogen. However, we are also of the opinion that, at lower levels of exposure, formaldehyde must be considered in a realistic context, and factors such as the quantitative relationship of exogenous formaldehyde to the metabolic pool and the rapid metabolism of formaldehyde as a normal body constituent must be taken into account.

Importance of Ongoing Studies

Further studies on formaldehyde that are in progress or about to be initiated are concerned with four major topics: work in nonhuman primates; a search for, and attempts to measure, possible specific adducts of formaldehyde with DNA; the effect of glutathione depletion on the intracellular toxicity of formaldehyde; and studies of the

absorptive capacity of the mucociliary apparatus in rats, monkeys and humans for formaldehyde.

Clearly, all of these studies are valuable for purposes of risk assessment because they throw light on the fundamental properties and mechanisms of action of formaldehyde. Perhaps of most immediate importance will be the application to monkeys of the techniques of molecular dosimetry developed for formaldehyde-exposed rats. Along with measurements of effective dose in specific target molecules of the upper respiratory tract, samples of tissues from distant sites will be analysed. At the same time, histopathological changes, physiological adaptations and increases in cellular proliferation will be determined in relation to various exposure regimens. All these observations should help to indicate the degree to which rat data are applicable to nonhuman primates. Assessment of relevance to humans should be facilitated to a corresponding degree.

Conclusions

1. Formaldehyde at levels of 5.6 and 14.3 ppm by inhalation in rats and 14.3 ppm in mice produces squamous cell carcinomas in the nasal cavity. Exposure to 10 ppm does not elicit such tumours in hamsters. In the rats and mice local tissue injury occurred, whereas these effects were not observed in hamsters.

2. Formaldehyde does not elicit tumours at sites other than the nasal cavity in rats and mice. Inhalation of formaldehyde does not significantly increase blood levels of formaldehyde in rats or in human subjects. Studies of covalent binding of suitably labelled formaldehyde have not revealed such binding to DNA at distant sites (i.e. other than the nasal cavity) in rats.

3. While formaldehyde has been shown to be weakly genotoxic in several test systems *in vitro*, there is no substantive evidence that it is mutagenic in mammalian systems *in vivo*. The nasal mucosal epithelium has not been studied in this regard. This lack of clear evidence of genotoxicity *in vivo* may be explained by the rapid metabolism of formaldehyde in intact animals.

4. Taken individually or as a group, the numerous epidemiological studies have failed to demonstrate a relationship between formaldehyde exposure and

nasal cancer or pulmonary diseases such as emphysema or lung cancer. Increased incidence of brain tumours, along with tumours at other sites has been noted in certain professional groups, i.e. anatomists, pathologists and morticians exposed to formaldehyde and other agents, but not, apparently, in laboratory technicians and industrial workers. The aetiological relationship of these tumours to formaldehyde exposure is uncertain.

5. In view of the considerations enumerated above, risk assessment is based primarily on the tumours in rats, but takes into account the observations on exposed population groups. While it is clear that formaldehyde administered to rats at concentrations in excess of 6 ppm induces damage to DNA and extensive structural and functional changes in the nasal epithelium, the available evidence suggests that these effects do not occur at exposure levels of less than approximately 1 ppm. The C $\times$ t animal studies referred to above demonstrate that concentration, rather than duration of exposure, is the determining factor in formaldehyde-induced tissue damage and, by implication, carcinogenesis. Because of its irritant properties, it is unlikely that humans would be exposed to sufficient concentrations of formaldehyde over periods long enough to induce the tissue damage and the subsequent sequelae predisposing to the pattern of carcinogenesis observed in animals. Human experience has not indicated short-term effects, other than irritancy, at mean levels of exposure of 1 ppm or below. The available metabolic, pharmacokinetic and pathologic data in animals and/or humans suggest a basis for an occupational exposure level of 1 ppm TWA.

6. Establishment of a more definitive standard may be possible upon the completion of ongoing metabolic and epidemiological studies.

Résumé

Ce rapport examine les particularités marquantes des propriétés physiques, chimiques et biologiques du formaldéhyde qui déterminent la façon dont les humains et les animaux réagissent à ce composé. Ces divers facteurs, alliés à une analyse succinte des faits déjà publiés et des recherches en cours ont servi de base à des conclusions et à des recommandations relatives aux effets du formaldéhyde sur la santé.

Bibliography

Acheson ED, Gardner MJ, Pannett B, Barnes HR, Osmond C, Taylor, CP. Formaldehyde in the British chemical industry. Lancet 1984; 8377:611–16.

Albert RE, Sellakumar AR, Laskin S, Kuschner M, Nelson N. Gaseous formaldehyde and hydrogen chloride induction of nasal cancer in the rat. J Natl Cancer Inst 1982; 68:597–603.

Andersen I, Molhave L. (1983). Controlled human studies with formaldehyde. In: Gibson JE, ed. Formaldehyde Toxicity. Chemical Institute of Toxicology, Hemisphere Publishing Co. 1983:154–65.

Casanova-Schmitz M, Heck H d'A. DNA-Protein cross-linking induced by formaldehyde (FA) in the rat respiratory mucosa: Dependence on FA concentration in normal rats and in rats depleted of glutathione (GSH). Abstract of paper to be presented at the Society of Toxicology Meetings in San Diego, March 1985.

Casanovâ-Schmitz M, Star TB, Heck H d'A. Differentiation between metabolic incorporation and covalent binding in the labeling of macromolecules in the rat nasal mucosa and bone marrow by inhaled [^{14}C] − and [^{3}H] formaldehyde. J Toxicol Appl Pharmacol 1984; 76:26–44.

Dalbey WE. Formaldehyde and tumors in hamster respiratory tract. Toxicology 1982; 24:9–14.

Harrington JM, Oakes D. Mortality study of British pathologists 1974–80. Br J Ind Med 1984; 41:188–91.

Heck H d'A, Casanova-Scmitz M, Dodd PB, Schacter EN, Witek TJ, Tosun T. Formaldehyde (CH_2O) concentrations in the blood of humans and Fischer-344 rats exposed to CH_2O under controlled conditions. J Am Ind Hyg Assoc 1985; (in press).

Hoel DG, Kaplan NL, Anderson MW. Implication of nonlinear kinetics on risk estimation in carcinogenesis. Science 1983; 219:1032–37.

International Agency for Research on Cancer. Mongraphs on the evaluation of the carcinogenic risk of chemicals to humans. IARC Monographs 1982; 29:345–89.

Kerns WD, Pavkov KL, Donofrio DJ, Swenberg J. Carcinogenicity of formaldehyde in rats and mice after long-term inhalation exposure. Cancer Research 1983; 43:4382–92.

Levine RJ, Andjelkovich DA, Shaw LK, Dalcorso RD. Mortality of Ontario undertakers: a first report. In: Clary JJ, Gibson JE, Waritz RS, eds. Formaldehyde: toxicology, epidemiology and mechanisms. New York: Marcel Dekker, Inc, 1983:127–40.

McMartin KE, Martin-Amat G, Noker PE, Tephly TR. Poisoning v. role of formate metabolism in the monkey. J Pharmacol Exp Therapeut 1977; 201:564–572.

McMartin KE, Martin-Amat G, Noker PE, Tephly TR. Lack of role for formaldehyde in methanol poisoning in the monkey. Biochem Pharmacol 1979; 28:645–49.

Morgan KT, Patterson DL, Gross EA. Frog palate mucociliary apparatus: structure, function and response to formaldehyde gas. Fund Appl Toxicol 1984; 4:58–68.

O'Berg MT. Formaldehyde and cancer: an epidemiologic perspective. Advances in Chemistry Series 1985; (in press).

Pell S, *et al.* Cancer epidemiologic surveillance in the DuPont Company. J Occup Med 1978; 20:725–40.

Rusch GM, Clary JJ, Rinehart WE, Bolte HF. A 26-week inhalation toxicity study with formaldehyde in the monkey, rat, and hamster. Toxicol Appl Pharmacol 1983; 68:329–43.

Starr TB, Buck RD. The importance of delivered dose in estimating low-dose cancer risk from inhalation exposure to formaldehyde. Fund Appl Toxicol 1984; 4:740–53.

Starr TB, Gibson JE, Barrow CS, *et al.* Estimating human cancer risk for formaldehyde: critical issues. Paper presented at the American Chemical Symposium on Formaldehyde Toxicology April 9–12, 1984, St. Louis, Mo.

Swenberg JA, Kerns WD, Mitchell RI, Gralla EJ, Pavkov KL. Induction of squamous cell carcinomas of the rat nasal cavity by inhalation exposure to formaldehyde vapor. Cancer Res 1980; 40:3398–3402.

Swenberg JA, Gross EA, Randall HW, Barrow CS. The effect of formaldehyde exposure on cytotoxicity and cell proliferation. In: Clary JJ, Gibson JE, Waritz RS, eds. Formaldehyde Toxicology Epidemiology Mechanisms. New York: Marcel Dekker 1983; 225–36.

Thomson EJ, Shackleton S, Harrington JM. Chromosome aberrations and sister-chromatoid exchange frequencies in pathology staff occupationally exposed to formaldehyde. Mut Res 1984; 141:89–93.

Walrath J, Fraumeni JF, Jr. Cancer and other causes of death among embalmers. Cancer Res 1984; 44: 4638–41.

Walrath J, Fraumeni JF, Jr. Mortality pattern among embalmers. International J Cancer 1983; 31:407–411.

Publications Available From the Government Book Store

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News and Notes

University of Toronto Workshop in Industrial Hygiene
September 23–27, 1985

The Seventh Annual Workshop in Industrial Hygiene, to be held at the University of Toronto, is designed for professional occupational hygienists who, perhaps as a result of specialization, feel the need for a general refresher course, for recent entrants to the hygiene field who wish to broaden their background knowledge and management, safety professionals and labour representatives who wish to rapidly acquire an understanding of industrial hygiene.

The Industrial Hygiene and Hazard Control Engineering Program of the University of Toronto is presenting the workshop in association with the Occupational and Environmental Health Unit, Faculty of Medicine, University of Toronto, and the Industrial Accident Prevention Association of Ontario.

Enquiries should be addressed to:

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Conference '85
14th Annual Ontario Occupational Health Nurses Association
L'Hotel, Toronto, Ontario
November 4th – 8th Inclusive, 1985

Date	Workshop Subjects
Monday and Tuesday November 4 and 5	• Physical Assessment: Part Five • Violence in the Family • Occupational Health and Safety Information Systems • The Occupational Health Nurse: Solo • 'You Ought to Publish That' • Human Rights and Placement of Employees

(continued)

Date	Workshop Subjects
	• Health Promotion Programs in the Workplace

Date	Conference Titles and Speakers
Wednesday, Thursday and Friday November 6, 7 and 8	'Towards Strong and Effective Leadership – A Challenge' Senator Lorna Marsden
	'The Practical Aspects of Power' Sheila Ward
	'Dignity for Women in Health Care' Mary Vachon
	'Computer Technology in Occupational Health' Lori Thompson
	'The Challenge of Transcultural Nursing' Eleanor Pask
	'Update on Diagnostic Imaging' Panel – Toronto Institute of Medical Technology
	'Effective Techniques in Adult Teaching' Carole Woods
	'Oncology Update' Panel – Princess Margaret Hospital
	'Nurses Dilemma – ''All Things to All People'' ' Dr. Ben Schlesinger

Cost of Conference		
Full Conference:	Members	$150.00
	Non-Members	$225.00
Daily Fee:	Members	$ 60.00
	Non-Members	$125.00
Workshops:	Members	$100.00
	Non-Members	$150.00
Registration	Anne-Marie Coyle 49 Fieldwood Drive Scarborough, Ontario M1V 3G3	

Coming Events

August 18 – 24, 1985	Health Care Expo '85. WASHINGTON, D.C.
September 1 – 5, 1985	Second International Conference of the International Society for Respiratory Protection. University of York. YORK, ENGLAND.
September 2 – 6, 1985	Ninth Congress of the International Ergonomics Association – c/o Congress Secretariat, Meon House, Petersfield Hampshire GU32 3JN, U.K. Tel.: 0730 66561 Telex: 86181 Meon G. BOURNEMOUTH, ENGLAND.
September 2 – 6, 1985	Sixth International Symposium on Inhaled Particles 1985 – Dr. N.P. Crawford, Institute of Occupational Medicine, 8 Roxburgh Place, Edinburgh EH8 9SU, Scotland, U.K. Tel.: 031-667 5131. CAMBRIDGE, ENGLAND.
September 10 – 12, 1985	Fourth International Symposium on Epidemiology in Occupational Health. Dr. P.A. Bertazzi, Secretary, IV International Symposium, Epidemiology in Occupational Health, 8 Via S. Barnaba, 1–20122 Milan, Italy. Tel.: (02)581610. COMO, ITALY.
September 10 – 13, 1985	Second National Conference on Occupational Medicine and Annual Meeting of the OMAC and Canadian Board of Occupational Medicine. Contact – Dr. J.W. Cowell, President, OMAC, c/o Nova, an Alberta Corporation, P.O. Box 2535, Station M, Calgary, Alberta, T2P 2N6. CALGARY, ALBERTA, CANADA.
September 16 – 20, 1985	Golden Jubilee of the Society of Occupational Medicine, BIRMINGHAM, ENGLAND.
September 17 – 20, 1985	Twelfth International Colloquium on the Prevention of Occupational Risks in the Construction Industry. Contact Secretariat of the Colloquium. Bau-Berufsgenossenschaft Hamburg. Holstenwall 8–9, D–2000 Hamburg 36 (Federal Republic of Germany). HAMBURG, GERMANY.
September 19 – 21, 1985	The Challenge of the Lumbar Spine – Seventh Annual Meeting. Contact: Devi Segal, Program Co-ordinator, The Institute for Low Back Care, 2737 Chicago Ave., Minneapolis, MN 55407, Tel.: (612) 874-6666. Amfac Hotel, MINNEAPOLIS, MINNESOTA.

September 23 – 25, 1985	Radioactive Waste Management. WINNIPEG, MANITOBA, CANADA.
September 26 – 27, 1985	Information Meeting, Canadian Nuclear Fuel Waste Management Research Program. WINNIPEG, MANITOBA, CANADA.
October 1 – 3, 1985	Ventilation '85, First International Symposium on Ventilation for Contaminant Control, Royal York Hotel, TORONTO, CANADA. For details contact Dr. H.D. Goodfellow, Hatch Associates Limited, 21 St. Clair Avenue East, Toronto, Ontario, Canada M4T 1L9.
November 18 – 21, 1985	International Symposium on Ergonomics in Developing Countries. JAKARTA, INDONESIA. Further information may be obtained from: International Labour Office, Occupational Safety and Health Branch CH–1211 Geneva 22.

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